XXI. *Flame Spectra at High Temperatures.*—Part III. *The Spectroscopic Phenomena and Thermo-Chemistry of the Bessemer Process.*

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[Plate 14.]

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Introduction and Historical Notes.

It is well known that the flame which issues from the mouth of the converting vessel used in the manufacture of steel by the Bessemer process has a very peculiar character; in the first place it is intensely luminous, and of a singularly greenish-yellow hue at one phase of its existence, but subsequently the tint of the flame is amethyst coloured.

In February, 1863, Sir H. E. Roscoe ('Literary and Philosophical Society of

Manchester Proc.,' vol. 3, p. 57) stated that he had been engaged during the previous year in an interesting examination of the spectrum produced by this flame, and had observed a complicated but characteristic series of bright lines and dark absorption bands. The well-known sodium, lithium, and potassium lines were most conspicuous among many other lines of undetermined origin. In a lecture delivered at the Royal Institution (May 6th, 1864) he described the Bessemer flame spectrum more fully, and pointed out the existence of lines which he believed to be due to the elements carbon, iron, sodium, lithium, potassium, hydrogen, and nitrogen. These observations led to the discovery that the exact point of decarburization of the metal could be determined by means of the spectroscope with much greater exactitude than from the mere appearance of the flame, and for determining the point at which it was necessary to stop the blast this instrument was in constant use at Sheffield in 1863, and was introduced into the steel works of the London and North-Western Railway Company at Crewe ('Phil. Mag.,' vol. 34, p. 437, 1867).

F. KOHN, in a lecture ('DINGLER'S Polytech. Journal,' vol. 175, p. 296) delivered in 1864, on recent improvements in the Bessemer process, stated that endeavours to make spectrum analysis applicable to the Swedish process had not led to any useful result. TUNNER, in 1865 ('DINGLER'S Polytech. Journal,' vol. 178, p. 465), stated that up to the close of the previous year the observations of the flame and sparks issuing from the converter and test pieces of the metal, gave better indications than spectrum analysis. In 1867, LIELEGG made observations on the spectrum of the Bessemer flame at the works of the Imperial Southern Railway at Gratz ('Sitzungsberichte der Kaiserl. Akademie der Wissenschaften,' Vienna, vol. 56, Part II., June), which led to the practical application in Austria of the use of the spectroscope to the control of the Bessemer process. The spectrum, as described by LIELEGG, consists of the vapours of sodium, potassium, and lithium, with that of the flame of carbonic oxide. Accompanying the latter gas is nitrogen, but no spectrum of this gas appears, nor could any spectrum of it be obtained by burning compounds which did not contain nitrogen, along with atmospheric air. It was also shown that though carbon spectra are obtained by burning hydrocarbons and cyanogen, with air or oxygen, yet carbonic oxide yields no such spectrum. Carbonic oxide was found to yield only a continuous spectrum when burnt with air or oxygen, or even with nitrous oxide. No dark or bright lines were visible. It was represented that the bright lines in the Bessemer flame must result from the much higher temperature which is produced by combustion of the heated gas at the mouth of the converter, than when laboratory experiments are performed with the same gas.

The spectrum as it occurs in the "boil," and up to the end of the "fining" period, was described as follows. The figures are arbitrary scale measurements :—

	259.	Red potassium line.
	233.	Red lithium line.
α.	212. 210. 208.	Group of three narrow red lines, of which the first and third are well seen.
	201.	Yellow sodium line.
β.	195. 190. 184.	Group of three greenish lines, of which the third (184) is the brightest and always appears first; sometimes the space between 199–195 filled with greenish-yellow lines.
	174. 172·5. 171·5.	Group of three pea-green lines, the third (171·5) is the brightest and the first to appear.
δ.	162. 160. 158. 155·5.	Group of four greenish-blue lines, of equal or similar brightness.
ε.	148. 144·5. 141. 136·5.	Groups of four equally bright blue lines.
	113.	End of a group of many blue lines equally separated from each other, which are closely adjacent to the foregoing group. These lines are much weaker, and can always be observed.
	81. 67.	The edges of a group of blue-violet double lines, which first make their appearance in the "fining" stage, but not always markedly.
	41.	Clearly defined blue-violet lines; it appears first in the "fining" stage simultaneously with the group preceding it (81 and 67).
	4.	Violet potassium line.
η.	(2.)	Bright violet lines.

The groups β, γ, δ, and ε are not composed of lines but bands, and together with the lines at η are characteristic of the Bessemer "blow." Especially are the following three lines conspicuous: 184 of the group β, 171·5 of group γ, and the violet η (2); they are the most sensitive, and they appear in the spectrum when carbonic oxide enters into the flame, indicating the commencement of the second period, as also their vanishing at the end of the process allows of the complete decarburization being recognised. That the lines from 113 to 41 belong to carbonic oxide could not be determined with equal exactitude, though it appeared to be probable. Many bright lines undetermined and several dark bands supposed to be due to absorption were noticed which had, however, no practical interest. LIELEGG described the changes in the spectrum at different stages of the process. It is to be noted that he attributes the bands, or lines as he terms them, to carbonic oxide.

MARSHALL WATTS, in 1867 ('Phil. Mag.,' vol. 34, p. 437), communicated an account of a lengthened examination of the Bessemer spectrum made at the works of the London and North-Western Railway, at Crewe, which had extended itself into an inquiry into the nature of the various spectra produced by carbon compounds.

It was noticed that after lines of the alkali metals had become visible, an immense number of lines were seen, some as fine bright lines, others as intensely dark bands. Striking evidence was afforded of the cessation of the removal of carbon from the iron by the disappearance of nearly all the dark lines and most of the bright ones. The spectrum was stated to be remarkable from the total absence of lines in the more refrangible portion; it extended scarcely beyond the solar line b^3. It was found indispensable that the spectrum should be actually compared with the spectra of the elements sought for. The spectrum of the Bessemer flame was accordingly compared with the following spectra:—

(1.) Spectrum of electric discharges in a carbonic oxide vacuum.
(2.) Spectrum of strong spark between silver poles in air.
(3.) Spectrum of strong spark between iron poles in air.
(4.) The same in hydrogen.
(5.) Solar spectrum.
(6.) Carbon spectrum, oxy-hydrogen blow-pipe supplied with olefiant gas and oxygen.

The coincidences observed were very few and totally failed to explain the nature of the Bessemer spectrum.

The spectra of neither carbon, nor of carbonic oxide,* appeared in the Bessemer flame, either as bright lines or as absorption bands. Three lines were traced to iron and a dark absorption band in the red, due to hydrogen (line C), was visible more particularly in wet weather.

J. M. SILLIMAN ('Phil. Mag.,' vol. 41, p. 1) pointed out that the progress of the decarburization in the Bessemer process is determined chiefly by the appearance of the smoke, flame, and sparks emitted from the converter, and that owing to the rapidity with which the changes takes place it is highly important to catch the exact moment when the blast should be turned off. The colour and brightness of the stream of gas issuing from the converter when observed by an experienced eye, generally give a sufficient indication, but when pig iron of a highly manganiferous character is used, this determination is very difficult; even those who had had much experience made frequent mistakes, and found it impossible to produce the same quality of metal at every operation.

Mr. ROWAN, of the Atlas Works, Sheffield, made use of coloured glasses, two of ultramarine blue and one of dark yellow, by which the eye was greatly assisted and the termination of the process rendered unmistakeable.

Though LIELEGG first recognised the fact that the spectrum of the Bessemer flame was not the spectrum of carbon, nor entirely that of carbonic oxide, which gives a continuous spectrum, it was BRUNNER in 1868 who first expressed the view that the spectroscope cannot be considered as a practical indicator of the decarburization in the Bessemer process, because the lines of the Bessemer spectrum do not belong to carbonic oxide or to carbon, but to manganese and other elements in the pig-iron ('Oesterreichische Zeitschrift für Berg- und Hütten-wesen,' vol. 16, 1868, pp. 226, 228).

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* It does not appear that WATTS examined the flame of carbon monoxide burnt with air or with oxygen.

Next, VON LICHTENFELS ("Ein Beitrag zur Analyse des Spectrums der Bessemerflamme," 'DINGLER'S Polytech. Journal,' vol. 191, pp. 213, 215) remarked that the nature of the several green and blue groups of lines seen in the Bessemer spectrum was not known; they had been attributed to various substances, but with no certainty as to their identity. SIMMLER had described the spectrum of manganese as consisting of four broad green bands and a violet line lying near to the violet potassium line ('Zeitschrift für Analytische Chemie,' 1862); and VON LICHTENFELS, examining the spectrum of manganous chloride dissolved in alcohol, found the green bands to be composed of groups of lines, the constituent rays of which corresponded exactly with the constituent lines in the groups of the Bessemer spectrum. He concluded that the groups of green lines seen in the Bessemer spectrum belonged to manganese.

J. SPEAR PARKER made a number of observations at the works of Messrs. CHARLES CAMMELL and Co., of Sheffield ('Chemical News,' vol. 23, p. 25) with coloured glasses and with the spectroscope. He was unable to confirm LIELEGG'S statement that the Bessemer spectrum could be seen when the converter was merely being heated. He thought the spectrum could not be attributed to manganese as it had been, and was of opinion that the most characteristic portion of it would be found to be owing to the presence of carbon in some form.

KUPELWIESER, in a special lecture delivered at the Berg-Akademie at Leoben on the application of the spectroscope to the Bessemer process, quotes LIELEGG'S observations, and assigns reasons for believing his conclusion to be correct when he attributed the Bessemer spectrum to carbonic oxide. The lines belonging to carbonic oxide first make their appearance when the temperature of the converter has become greatly elevated and the carbon of the pig-metal commences to burn; they remain throughout the second and third periods until complete decarburization has taken place. They are brightest when the temperature is highest, and they vanish somewhat quickly along with the combined carbon, while they reappear when a proportion of molten pig-iron is added to the blown metal. The same lines are stated by KUPELWIESER to be visible, though not so conspicuously bright, when a converter is being heated with coke. Also when slag and metal are drawn off from the tap-hole of a blast furnace he had observed the carbon monoxide spectrum. By means of a SEFSTRÖM'S furnace he obtained spectra with the α, β, and γ groups in LIELEGG'S carbonic oxide spectrum ('Oesterreichische Zeitschrift für Berg- und Hütten-wesen,' p. 59, 1868, No. 8).

BRUNNER pointed out that the spectrum of carbonic oxide is not a line spectrum but a continuous band of rays, though LIELEGG believed the difference in the Bessemer spectrum is caused by the higher temperature of the latter; only old converters show the green group γ when being heated with coke, one with a new lining never does. The green lines of manganese he believed to be the constituents of the groups β and γ of LIELEGG's so-called carbonic oxide spectrum and also the violet line of manganese, the line η, attributed to carbonic oxide.

The flame from the tap-hole of a blast furnace could display the same spectrum as that of the Bessemer flame just as well if the spectrum be composed of lines of manganese and iron as if they were due to carbonic oxide. At the request of KUPELWIESER, SCHÖFFEL analysed the fume which rises from the neck of a converter during the "fining" period and found it to be a manganese and ferrous silicate.

$$\begin{aligned} SiO_2 &= 34{\cdot}86 \\ MnO &= 48{\cdot}23 \\ FeO &= 16{\cdot}29 \\ \hline &\quad 99{\cdot}38 \end{aligned}$$

This is an indication of manganese and iron being concerned in the formation of the spectrum ('Oesterreichische Zeitsch.,' No. 29, p. 227, 1868).

The investigation, carefully and laboriously carried out by Dr. MARSHALL WATTS, led him to the conclusion that the lines visible in the Bessemer-flame spectrum are mainly due to manganic oxide, not to metallic manganese, as had been stated, nor to carbon. When manganese chloride, carbonate, or oxide, such as the mineral pyrolusite, is heated in the oxyhydrogen flame, a very brilliant banded spectrum is obtained which is for the most part coincident with the Bessemer spectrum.

Observations were further made on the spectrum of the flame obtained on adding spiegel-eisen to Bessemer metal, on the temperature of the flame at different stages in the process, and on different spectra obtained by the employment of different kinds of iron.

Accurate determinations were made for the first time of the wave-lengths of lines observed in the spectra of the Bessemer flame of spiegel-eisen, and of manganese dioxide.

The fact that six lines of iron were present in the Bessemer spectrum was established, and considered to be a proof that iron may exist as vapour at a temperature below its melting-point, since certain experiments led to the conclusion that the Bessemer-flame was not hot enough to melt wrought-iron.

This work of MARSHALL WATTS is the most exhaustive investigation of the subject that has up to the present appeared. In 1874* GREINER observed in the flame from highly manganiferous pig-iron the spectrum of manganese as figured by WEDDING.

During the meeting of the British Association, at Sheffield, in 1879, I made a short examination of the Bessemer flame with a small direct vision spectroscope, at the works of Messrs. BROWN, BAYLEY, and DIXON; I also examined the flame of spiegel-eisen. This examination convinced me that the banded spectrum of carbon is never visible, and that the bands which are seen in the spiegel spectrum possess a feature which distinguishes them in a striking manner from the bands of carbon, namely, they are degraded towards the red, the carbon bands being degraded towards the blue. This had already been noticed by WATTS.

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* 'Revue Universelle,' vol. 35, p. 623, 1874.

Description of the Instrument used and the method of observing and photographing Spectra of the Bessemer Flame.

In 1882 I devised an instrument for meeting the requirements of a series of observations to be made at steel works, particularly for studying the spectra of flames, and the heated gases of open-hearth furnaces. It was desirable that it should give a fair amount of dispersion at the less refrangible end of the spectrum, be rigid and portable. A train of four quartz prisms was at first arranged on a table and stand made entirely of wood, to which a camera was fitted, with a rack and pinion movement to the frame holding the dark slide, so that several spectra could be photographed on one plate. Various trials with this mounting showed that owing to the stand being too light, the instrument was unsteady. In 1887 the quartz train was mounted on a heavy tripod stand. The prism table was fixed to the pillar of the stand by a winged screw joint and counterpoised, so that it could be placed in almost any required position. The camera was of metal, with an eye-piece behind the frame for the dark slide, so as to make it available for observations with the eye, for which it is peculiarly well adapted, owing to the observer having the flame behind him, and therefore he is not embarrassed by the glare. In the circular box at the end of the camera the dark slide can be fixed at any angle, as it is rotated by means of a toothed wheel. The collimator and telescope or camera are fitted with a scale of millims. on the draw-tubes, so that both the slide and photographic plate may be drawn out so as to be equi-distant from the lenses for the purpose of focussing correctly. The camera can be clamped, and its exact position determined by means of a divided arc on the prism table. A telescope with a photographic scale, which is reflected from the face of that prism which is nearest to the lens in the camera, has been found useful. The prisms move automatically with the camera, in order to secure the minimum angle of deviation for the mean rays photographed. A framework in front of the slit, and fixed to the prism table, carries a condensing lens of three inches focus. Latterly, a condenser with two cylindrical lenses crossed at right angles has been in use, a device which was described in a letter to the author by Herr VICTOR SCHUMANN. It has the advantage of giving a very sharp image of the lines, but it was not employed at Crewe, or at Dowlais, owing to the fitting being a delicate one, the adjustment requiring care, and the necessity which occasionally arises for cleansing the condensing lenses from time to time from dusty fume, or moisture, even during the progress of the "blow." With the usual form of condenser, an image of the flame was projected upon the slit, sometimes the flame was in the same vertical line with the slit, and sometimes placed diagonally. This depended very much upon the position of the converter and the consequent size of the image. The slit plate was covered with a thin plate of quartz to exclude dust and dirt. A metal plate with a V-shaped piece cut out of one end slides over this, and serves to shorten or lengthen the slit, and secure a greater or smaller number of spectra on one photographic plate. In some cases, a photograph was taken every half-minute, from the commencement to the termination of the "blow." This could be accomplished only by the use of such a contrivance, as the plates measured no more than $3 \times 2\frac{1}{2}$ inches.

To focus the instrument various photographs of sun-spectra were taken and the positions of the different adjustable parts were recorded. In order to render the instrument portable a case was constructed for carrying the prism table, prisms, collimator, and camera, without disarranging the adjustment of the instrument. A winged screw when loosened enabled the whole to be detached from the vertical pillar of the tripod, the counterpoise, of course, having been detached previously. The prism table was then fastened in its case. A second case carried the tripod, counterpoise, chemicals, and developing dishes. This case when empty had a square frame of wood which fitted into the top when the lid was open. The frame was covered with waterproof cloth, lined with yellow calico. In the cloth were arm-holes and sleeves fitted with elastic, which came half way up to the elbows. The developing dishes and measured quantities of solution were placed ready in the box and the dark slide could be opened, the plate removed and placed in the developer, while during development a new plate could be put into the slide. Development was always allowed to proceed for a given period which previous experiment had proved to be sufficient. During the progress of development the dish was covered with an ebonite tray to exclude any possibility of light reaching the photographic plate. By such means the plates are developed and fixed without the use of a dark room, but it is, of course, essential that the hands are not withdrawn from the box before the development is concluded. At Crewe my assistant had the use of a laboratory, but at Dowlais the operating box was always used.

Arrangements were made for carrying out the first series of observations from a point on the floor of the cupola-house at Crewe, situated close to the platform, from which the ladles of spiegel-eisen are tipped into the converters. The instrument was placed upon a very solid bench, which could, however, be moved about as required. From preliminary observations with a direct vision instrument it was decided to take photographs of the sun-spectrum at the laboratory, to sensitise some plates with cyanine, develop the sun-photographs, and, having obtained a good focus, to remove the instrument by hand to the cupola-house. It was considered best to photograph, first, the spectrum obtained during the whole period of the "boil," and, secondly, the blaze, after the addition of spiegel-eisen. Unfortunately the sun was not always visible, but on one occasion the spectra of the sun and of the flame from the converter, during four periods in one "blow," were secured on one plate. With this plate it was easy to see that a large number of lines were coincident with lines in the solar spectrum. Upon enlarged prints, some of which were 10 × 12 or 12 × 15 inches, made with gelatine-silver bromide paper, it was easy to record the position of the lines and edges of bands with respect to the sodium line, as these were measured with a micrometer screw and microscope in the manner already described ('Phil. Trans.,' 1894). It became necessary, however, to obtain enlargements of greater dimensions, and, accordingly, the Autotype Company were requested to make such, measuring 36 × 24 inches, in which the spectra were magnified ten diameters. These were easily examined and compared with ROWLAND's first map of the solar spectrum and with MACLEAN's photographed spark spectra of metals. These enlargements had another advantage than facility for recognising coincident lines, for, with a standard brass metre, the bands in the spectra were more easily measured than with the micrometer. Several interpolation curves were drawn by which linear measurements were reduced to oscillation-frequencies. These were necessary because the portion of the spectra less refrangible than H was differently focussed on some of the plates. The fiducial lines selected were 110 lines in the spectrum of iron, and in the solar spectrum, lying between D and P.

It was found to be almost impossible to measure the same bands on different spectra and obtain measurements giving identical wave-lengths. This will appear on referring to Plate 6, Crewe, and comparing the measurements of the first, second, and third spectra. Although there is some difficulty in obtaining measurements of bands so precise as we are accustomed to in line-spectra, this does not account for the discrepancy. It is, in point of fact, due to the bands altering in width, or, in some cases, becoming less distinct at the edges; the bands are also much obscured on some spectra by the continuous rays being strong. There is some difficulty also, it may be remarked, in measuring the broad lines visible in some of the banded metallic spectra ('Phil. Trans.,' Part I., 1894).

Observations made at Crewe and at Dowlais in 1893.

I am much indebted to Mr. F. W. WEBB, of the Locomotive Department of the London and North-Western Railway, and to Mr. E. P. MARTIN, the Manager of the Dowlais Iron Works, for facilities afforded me in carrying out a series of observations at Crewe and at Dowlais, in January and in April, 1893. In order to photograph the Bessemer flame, the instrument was placed on a strong, low bench, sufficiently near to the mouth of the converter and in a position of safety as regards sparks projected from the vessel, when the blow at times became somewhat wild. While my assistant made exposure of the plates at different periods according to instructions, the phenomena observed during the "blow" were noted by me. During the first seven minutes there is only a continuous spectrum. The sodium line then flashes out occasionally. The temperature is evidently low, not much above that of cast iron. Sparks of graphite and of iron are ejected, but these come from the burning of spray caused by the eruption of air from the molten metal within the converter. After seven minutes the spectrum of sodium is constant, at ten minutes the spectrum of lithium becomes visible. Neither the hydrogen lines nor those of potassium were as a rule visible. Two violet lines of potassium appear in all the photographs. During the "boil" the sparks are few and small, because the metal being much hotter and more liquid there is less spray. The flame is large and it burns with a steady roar. At Crewe, it generally possessed the greenish-yellow colour of the vapour of manganese, and maintained this colour until about three seconds before the termination of the process. Sometimes, however, the mouth of the converter showed, during the progress of the "boil," the amethyst-coloured flame for a foot or two, extending from its edge, and there was a further tinge of the same tint beyond the yellowish-green, and quite at the outside of the tip of the bright flame. The duration of the "blow" varied from fifteen to twenty-one minutes. The metal used was hæmatite pig-iron, and the steel made was intended for boiler plates and also for small tyres and wheels. In certain cases particulars are given, but this is not a matter of consequence in considering the spectra observed. In all, twelve plates were exposed, some of which were so entirely satisfactory as to render any further work at Crewe unnecessary, there being ample material for some months of study.

Spectra of the Bessemer Flame photographed at Crewe in January, 1893, *with a detailed account in each case of the period of the "blow," the plates used, and the duration of each exposure.*

PLATE 1.

The first exposure lasted three minutes. (EDWARDS' isochromatic instantaneous plate.)

A second exposure was made of another part of the plate, and a different "blow."

"Blow" started at	1.34 P.M.	
First appearance of Na line	1.41 ,,	
,, ,, red and green bands	1.45 ,,	
Exposure commenced	1.46 ,,	
Continued till end of "blow"	1.55½ ,,	
Duration of exposure		9½ minutes.

A third exposure.

"Blow" commenced at	3.38 P.M.	
First appearance of sodium line at	3.45 ,,	
,, ,, red and green bands	3.48 ,,	
Exposure began	3.51 ,,	
End of "blow"	3.57½ ,,	
Duration of exposure		6½ minutes.

The photographs were valuable as showing the extent of the spectrum, and occurrence of a large number of lines in the ultra-violet, which had never been observed in the Bessemer flame before. The plates had been much over-exposed.

Plate 2.

Edwards' isochromatic instantaneous plate, stained with cyanine.

	h.	m.	s.	Duration of exposure.
Commencement of the "blow"	9	55	0 A.M.	
1st exposure commenced at	10	1	30	5 minutes
2nd ,, ,, ...	10	6	30	3½ ,,
3rd ,, ,, ...	10	10	0	5 ,,
4th ,, ,, ...	10	15	0	1½ ,,
End of "blow"	10	16	30	

These photographs were not well focussed. The lithium red line and band near to it were just barely visible. The position of the image of the flame on the slit of the spectroscope was diagonal.

Plate 3. "Blow" 46. Boiler-plate.

Edwards' isochromatic instantaneous plate, stained with cyanine. The position of the image of flame on the slit plate was diagonal.

	h.	m.	s.	Duration of exposure.
Commencement of "blow" at	11	17	30 A.M.	
1st exposure began at	11	26	0	3 minutes
2nd ,, ,, ...	11	29	0	3 ,,
3rd ,, ,, ...	11	32	0	2 ,,

Plate 4. "Blow" 48. Boiler-plate.

Edwards' isochromatic instantaneous plate, stained with cyanine. The focus of the instrument was altered for different exposures by shifting the camera slide.

	h.	m.	s.	Duration of exposure.
Commencement of "blow"	1	46	30 P.M.	
Appearance of the sodium line at	1	53	0	
1st exposure at	1	55	0	2½ minutes
2nd ,, ...	1	57	30	2¼ ,,
To	1	59	45	
3rd exposure at	2	0	0	2 ,,
4th ,, ...	2	2	0	1¾ ,,
End of "blow"	2	3	45	

PLATE 5. "Blow" 50. Boiler-plate.

EDWARDS' isochromatic instantaneous plate, stained with cyanine.

	h.	m.	Duration of exposure.
"Blow" commenced at	4	0	
1st spectrum, exposure commenced at	4	4	4 minutes
2nd ,, ,, ,, ...	4	8	3 ,,
3rd ,, ,, ,, ...	4	11	
4th blaze from spiegel-eisen			
End of "blow"	4	16	

At the second exposure the blowing became very wild, and large quantities of metal or slag were thrown out of the vessel.

These photographs were in very fine focus all through ; the violet line of manganese appears distinctly divided into three lines. The bands in the yellow and red are well focussed.

PLATE 6. "Blow" 65. Rods. Vessel No. 2.

The image of flame on the slit was vertical. The plate used was an Ilford instantaneous one stained with cyanine.

	h.	m.	Duration of exposure.
Commencement of "blow"	9	38	
1st exposure	9	41	5 minutes
2nd exposure, the sodium line persistent	9	46	5 ,,
3rd ,, ,, ,, ,, ...	9	51	3 ,,
4th ,, ,, ,, ,, ...	9	54	3 ,,
5th ,, ,, ,, ,, ...	9	$57\frac{1}{2}$	$3\frac{1}{2}$,,
6th ,, ,, ,, ,, ...	10	1	$1\frac{1}{4}$,,
End of "blow"	10	$2\frac{1}{4}$	

The red and green bands were first seen at 9.50 A.M.

PLATE 7. "Blow" 67. Vessel No. 2.

Position of the image of the flame on the slit of the instrument, diagonal. An Ilford instantaneous plate, not stained, was used.

	h.	m.	Duration of exposure.
"Blow" commenced	11	36	
1st exposure from 11.36 to	11	39	3 minutes
2nd ,, ...	11	$48\frac{1}{2}$	$8\frac{1}{2}$,,
3rd, flame of spiegel-eisen.			
"Blow" ended	11	56	

The red and green bands first appeared at 11.46 A.M. The lines are distinct at the beginning of the second exposure.

This plate had each spectrum finely focussed all through. The spectrum of the spiegel-eisen was shown by the band in the greenish-yellow, and the pair of lines in the violet. The importance of these violet lines as a leading feature of the manganese spectrum is thus demonstrated.

PLATE 8. "Blow" 69. Small tyres and rails. Vessel No. 2.

The position of the image of the flame on the slit was vertical. An Ilford isochromatic plate, not stained. A sun spectrum was photographed with 15 seconds exposure. (See Plate 14, lower spectra.)

	h.	m.	Duration of exposure.
Commencement of "blow"	1	32	
1st exposure at	1	40	4 minutes
2nd "	1	44	3 "
3rd "	1	47	2 "
End of "blow"	1	49	

This is a very useful series of spectra, the focus being good and the sun spectrum being convenient for comparison. The manganese bands are well seen, and all the lines extending into the ultra-violet. This plate was enlarged 10 diameters for convenience in identifying the lines.

PLATE 9. "Blow" 71. Small tyres and rails. Vessel No. 2.

The image of the flame was diagonal on the slit of the spectroscope. An Ilford instantaneous plate was used, without stain.

	h.	m.	Duration of exposure.
Commencement of "blow"	3	33	
1st exposure, the sodium line seen at	3	39	4 minutes
2nd "	3	43	3 "
3rd "	3	46	1 "
4th "	3	47	1 "
5th "	3	48	2 "
End of "blow"	3	50	

This series was well focussed all through.

Plate 10. "Blow" 89. Vessel No. 2.

Position of flame on the slit, diagonal. An Ilford instantaneous plate, not stained, was used.

	h.	m.	Duration of exposure.
Commencement of the "blow"	11	5	
The sodium line appeared at	11	12	
1st exposure, both potassium and lithium lines were visible	11	16	4 minutes
2nd exposure	11	20	3 ,,
The "blow" was stopped at	11	23	
The converter was lowered in order to throw in scrap to cool the metal, which had become too hot.			
"Blow" started again at	11	$25\frac{1}{2}$	
3rd exposure	11	27	3 ,,
4th exposure commenced at	11	30	
End of "blow"	11	50	20 secs.

The duration of the 4th exposure was only 20 seconds. This is an excellent series of spectra.

Plate 11. "Blow" 90. Vessel No. 3.

The flame fell diagonally on the slit. The plate used was one of Edwards' isochromatic instantaneous make, stained with cyanine.

The camera was adjusted so as to bring the red end of the spectrum into sharper focus.

	h.	m.	secs.	Duration of exposure.
Commencement of "blow" at	12	31	30	
This was a larger charge than usual.				
The sodium line appeared at	12	40	0	
The lithium line at	12	43	0	
1st exposure at	12	46	30	85 secs.
2nd exposure commenced at	12	51	45	$5\frac{1}{4}$ minutes.
Ended at	12	57	0	

The spectrum of another "blow" was photographed on this plate. "Blow" 91. Vessel No. 1.

The position of the flame as before.

	h.	m.	secs.	Duration of exposure.
Commencement of the "blow" at	1	22	0	
1st exposure at	1	33	0	
Continued till	1	35	30	3 minutes
2nd exposure	1	38	15	
Continued till	1	44	30	$4\frac{1}{2}$,,
The "blow" was interrupted and the converter turned down at	1	35	30	
And up again at	1	37	45	

PLATE 12. "Blow" 92. Vessel No. 3. Rails.

	h.	m.	Duration of exposure.
Commencement of "blow" at	2	57	
Appearance of sodium flame at	3	6	
Appearance of red and green bands	3	9	
1st exposure at	3	10½	1½ minutes.
2nd exposure at	3	12	5 "
End of "blow" at	3	17	

Photographs of Bessemer-Flame Spectra taken at Dowlais Iron Works, South Wales, April, 1893.

The quantity of metal blown at Dowlais was larger than at Crewe, the converters were capable of taking twenty tons of metal at each charge, and the actual quantity blown was twelve tons. The pig iron, smelted from Spanish ore, contained about 1 per cent. of manganese, and 2 to 2½ per cent. silicon, with from 3½ to 3¾ per cent. of carbon. The blowing was generally very rapid, and owing to this circumstance, and the heavy charges of metal, there was an immense quantity of fume, which was carried by an easterly wind directly towards the instrument. Sometimes we were completely enveloped in dust from the fume. The lenses became coated with dust and with moisture caused by the condensation of steam, and hence the flame and the slit were obscured. Observations were carried on with great inconvenience, which would not have been the case had the wind been blowing from another direction.

PLATE 1.

The plates used were specially prepared by THOMAS and Co., Limited, of Pall Mall, London. They were stained with cyanine.

	h.	m.	
1st exposure	11	12 A.M.	
"Blow" stopped at	11	14	Exposure 2 minutes.

PLATE 2.

	h.	m.
"Blow" commenced at	11	48
Bands flashing out at	11	54
1st exposure (30 seconds)	11	56
Continuing to	11	56½

Blowing interrupted but re-commenced again at 12 h. 2 min. P.M. The bands are very brilliant.

	h.	m.
2nd exposure (2 minutes)	12	6½
Continuing to	12	8½
3rd exposure (2 minutes)	12	8½
Till	12	10½

PLATE 3.

	h.	m.
"Blow" commenced at	12	30
Bands flashing out at	12	34
The metal became too hot and the converter was turned down. An ingot mould was charged into it at	12	45
Blowing re-commenced at	12	47
1st exposure (3½ minutes)	12	49
To	12	52½
2nd exposure (2 minutes)	12	52½
To	12	54½

PLATE 4.

	h.	m.
"Blow" commenced at	1	20
Sodium line flashing out at	1	22
Lithium line ,, ,,	1	23
The continuous spectrum was extremely brilliant, the lines and the manganese bands seen upon the continuous spectrum were very intensely brilliant. The metal was too hot, and the converter was turned down at	1	26
Blowing re-commenced at	1	30
1st exposure (1 minute) at	1	31
2nd ,, ,, ,,	1	32
3rd ,, ,, ,,	1	33
4th ,, ,, ,,	1	34
End of "blow"	1	35

PLATE 5.

	h.	m.	s.
"Blow" began at	2	3	0
The sodium line flashed out at	2	6	0
The manganese bands flashed out at	2	7	30
1st exposure (30 seconds) at	2	9	30
"Blow" interrupted, converter turned down at	2	10	0
Blowing re-commenced	2	17	15
2nd exposure (30 seconds) at	2	18	0
Till	2	18	30
3rd exposure (3 minutes) at	2	20	0
Till	2	23	0

PLATE 6.

Received four exposures of 1 minute to 1½ minute each, but there was nothing of any use upon the plate. In all probability this was owing to the large body of fumes formed when the converter was turned down before the plate had been exposed. The metal was too hot, as may be readily understood from the fact that the manganese bands were flashing only 4½ minutes after the commencement of the blow.

PLATE 7.

The same remark applies to this plate. The photograph was not satisfactory.

The preceding work had been carried on in the open air, but it was considered better to move to the old Bessemer plant and be under cover, and away from the clouds of fume which were driven towards one by the wind, which still continued to blow from the east. Hot blast, grey pig iron, containing not less than 2 per cent. of silicon and from $3\frac{1}{2}$ to $3\frac{3}{4}$ per cent. of carbon, was being blown for the production of tin-plate iron. Charge of metal 10 tons.

The position of the instrument was about 4 feet above the mouth of the converter and 6 feet from it.

PLATE 8.

Blowing commenced at 10 hrs. $52\frac{1}{2}$ min. A.M., but the blast was stopped because of blowing going on at the other plant. The blast was turned on again at 12 o'clock, the manganese bands flashed out at 12 hrs. 5 min. P.M., and up to this the flame was nothing but that of carbonic oxide with the usual alkali metals.

	h.	m.	s.		h.	m.	s.
1st exposure (1 minute) at	12	7	30	to	12	8	30
2nd ,, (1 minute 10 seconds) at	12	8	30	,,	12	9	40
3rd ,, (30 seconds) at	12	9	40	,,	12	10	10
4th ,, (1 minute) at	12	10	10	,,	12	11	10
5th ,, (3 minutes) at	12	11	10	,,	12	14	10
6th ,, (2 minutes) at	12	15	0	,,	12	17	0

At the highest temperatures the flame was perfectly transparent.

A great quantity of fume, which condensed to coarse dust, was blown about, and much of this fell into the water used in washing the plates, and on the gelatine films. This could not be avoided, for it was necessary to develop the photographs on the spot and wash them as soon as developed.

PLATE 9.

The same metal as before. Blowing commenced at 12 hrs. 3 min. P.M.

	h.	m.		h.	m.
1st exposure from	12	9	to	12	10
2nd ,, ,,	12	10	,,	12	11
3rd ,, ,,	12	11	,,	12	12
4th ,, ,,	12	12	,,	12	13
5th ,, ,,	12	13	,,	12	14
6th ,, ,,	12	14	,,	12	15
7th ,, ,,	12	15	,,	12	16
8th ,, ,,	12	16	,,	12	17
9th ,, ,,	12	17	,,	12	18
10th ,, ,,	12	18	,,	12	$19\frac{1}{2}$
"Blow" ended.					

This plate was badly fogged.

PLATE 10.

Blowing commenced at 12 hrs. 45 min. P.M.
"Blow" interrupted at 12 hrs. 49 min.
Blowing re-commenced at 12 hrs. 55 min.

	h.	m.	s.		h.	m.	s.
1st exposure at	12	58	30	to	12	59	30
2nd ,, ,,	12	59	30	,,	1	0	30
3rd ,, ,,	1	0	30	,,	1	1	30
4th ,, ,,	1	1	30	,,	1	2	30
5th ,, ,,	1	2	30	,,	1	3	30
6th ,, ,,	1	3	30	,,	1	4	30
7th ,, ,,	1	4	30	,,	1	5	30
8th ,, ,,	1	5	30	,,	1	6	30
9th ,, ,,	1	6	30	,,	1	7	30
10th ,, ,,	1	7	30	,,	1	8	30
11th ,, ,,	1	8	30	,,	1	9	0

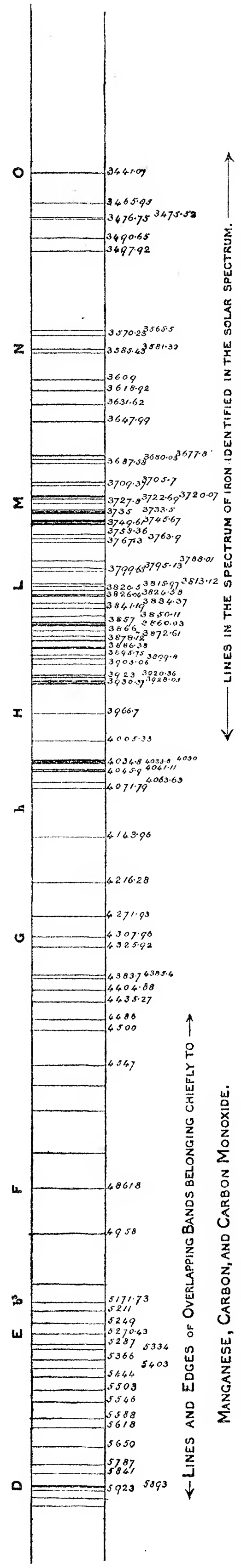
End of "blow."

SPECTRA OF THE BESSEMER FLAME.

Description of the Spectrum of the Bessemer Flame, as photographed at Crewe, January, 1893, *at the Steel Works of the London and North-Western Railway Company.*

The lines of the alkali metals appear, and are, in fact, the only prominent lines during the first period of the "blow," when the silicon is being oxidised and slags are in course of formation. During the second period, or the "boil," the flame exhibits a continuous spectrum of bright rays, overlying which is a number of bright bands; some of these appear to be degraded towards the least refrangible rays, others do not appear to be degraded, but are bounded by lines, or by very narrow bands, possibly by the sharp edges of bands. There does not appear to be any distinct fading away of bands in the direction of the least refrangible rays more than towards the blue. At the commencement of the "boil" the bands are not so numerous as afterwards, nor are the lines so strong and numerous as subsequently, excepting the lines of the alkali metals. It is noticeable that certain lines appear only at the commencement of the "boil," others do not appear until the end. There is no very great difference between the spectra taken at the close of the "boil," and at the commencement of the third period, or "fining stage." But both in the second and third periods there are several lines which are short, and seen only at the base of the flame; others are broad at the base of the flame, like bands, but towards the tip they attenuate into lines. By far the greater number of the lines in the spectra are iron lines; especially rich in these lines is the ultra-violet region. The prominent bands, for the most part occupying the region of less refrangibility than λ 3000, are due to metallic manganese. They

MAP OF THE BESSEMER FLAME SPECTRUM.



do not appear quite similar to the bands of the metal, nor of pure compounds of manganese, and this is partly owing to the continuous spectrum of carbon monoxide, partly to carbon bands, such as are exhibited in hydrocarbon flames, and also in part to bands of iron. This will be readily understood from an examination of the photographs and the wave-lengths of the edges of carbon bands, for it is evident that as the bands of carbon overlie those of manganese, the latter are most certainly obscured by the former, and the former by the latter; because, while the former consist of narrow bands degraded towards the violet, the latter are composed of similar narrow bands degraded towards the red. One overlying the other can produce the appearance of a broad band, which is not degraded, but appears as a continuous spectrum, and in this the only part distinguishable is the more refrangible edge of the manganese band, and the less refrangible edge of that of carbon. Between the two, neither bands nor lines can be distinguished if the rays are strong. There are some few lines due to carbon monoxide, and certain bands due to an oxide of manganese, either MnO or Mn_3O_4. It is not likely that MnO_2, which is easily decomposed by heat, could exist in the Bessemer flame; the vaporized oxide must be a substance of no small stability. References to the lines, measured by WATTS, have been inserted opposite to the line of nearest wave-length in the Bessemer spectra. Lines not identified by WATTS are either lines of iron, of manganese, or carbon bands. The lines of metallic manganese were not identified, probably because WATTS used manganese dioxide, or carbonate, for his comparison spectrum, instead of the metal heated in the oxyhydrogen flame.

Lines in the spectrum of the Bessemer flame, which are more refrangible than the solar line H, have not been examined before, and this portion of the spectrum is especially interesting. It extends to some small distance beyond the solar line O of CORNU'S *Spectre Normal*, or on some plates as far as P λ 3361·5. Most of the lines are very strong and sharp, forming very characteristic groups. They have nearly all been identified with iron; they are all strong lines, as seen in the arc spectrum of iron, and they are coincident with lines in the sun. They have been identified with the lines photographed from the spectrum of TURTON'S tool-steel, but steel in the oxyhydrogen blow-pipe yields no greater number of iron lines than occur in the Bessemer flame. Ferric oxide, under the same conditions, exhibits a spectrum with a band, and still fewer lines. It certainly appears as if the temperature of the Bessemer metal during the "boil" is as high as, or approaches that of, the oxyhydrogen blow-pipe flame, when the oxygen contains 10 per cent. of nitrogen, as the commercial oxygen supplied to us was found to do, and the flame is being used for spectroscopic purposes in the manner already described ('Phil. Trans.,' 1894.) Owing to the complicated nature of the spectra, the wave-lengths of bands and lines exhibited during different periods of the "blow" have been tabulated, with a description of each feature of the spectrum to which the measurements belong, and in parallel columns there are references to WATTS' measurements, and those of other investigators. This is, however, insufficient for an analysis of the spectra, and it has, therefore, been found necessary to state the wave-lengths of lines and bands with the wave-lengths of other lines with which they have been identified.

Lastly, it may be remarked that there have been very few instances of reversals noticed. Thus, at Crewe, forty-three photographs were taken on twelves plates, and, at Dowlais, forty-eight photographs on ten plates; of these, only forty of the latter series were sufficiently well-defined for examination; but only on one plate, No. 2, of the Crewe series, were the C line of hydrogen, the F line, hydrogen, and a line at N, seen reversed. The alkali metals showed no reversals.

PLATE 2.—Crewe. Spectrum 3.

λ.	Description of spectrum.	Remarks and lines for comparison.
6707	Line lithium	
6635	Band extending to 6564	
6564	A reversed line. Hydrogen. Seen during a snow-storm. Coincident with the solar line C.	
6196	. . . . Band degraded towards the red	6204 More ref. edge of band. WATTS
5990		
5923	Band narrow like a line	
5893	Sodium line. Mean of the two. Coincident with D	

PLATE 8.—Crewe. (Plate 14.)

λ.	Description of spectrum.	Remarks and lines for comparison.
5876	A band frequently occurring here	
5872	Nebulous line, or indistinct less refrangible edge of band	5872 Two faint lines. WATTS
5865	. . . .	5865
5841	Apparently the less refrangible edge of a band in the 1st spectrum; a line, or more refrangible edge of a band in the 2nd spectrum, and the less refrangible edge of a band in the 3rd spectrum	5847 Maximum of light. WATTS
5787	Well defined line in 1st spectrum; more refrangible edge of band in the 2nd spectrum	5790 Strong line, brightest edge of the whole group. WATTS
5767	Line or edge of a band which extends stronger up to next measurement	
5718	Less refrangible edge of a band, not distinct but intense	
5704	Edge of band, intense, doubtful	5705 Fine line. WATTS
5672	,, ,, ,, In 1st spectrum only	
5655	More refrangible edge of band, indistinct. Not distinguished in 3rd spectrum	5644 Edge of band. WATTS
5634	An intense band of rays overlies the other bands	5634·7 Carbon. WATTS

Plate 8.—Crewe—(continued).

λ.	Description of spectrum.	Remarks and lines for comparison.
5629	Line or edge of band	5629 Carbon. Lecocq de Boisbaudran.
5625	Edge of band distinct, strong	
5618	More refrangible edge of band, with a line	
5611	A line or edge of band	
5608	Edge of band, indistinct	5607 Edge of band. Watts
5595	Edge of band	
5588	Edge of band, terminating the first strong group. Does not appear in the 2nd spectrum	5580 " " " 5585·5 Carbon. Edge of band. Watts
	Another measurement here gave 5579. Both are probably correct, but they occur in different spectra in the same plate	5585·4 Fe. Fievez and Thalén
5552		5547 } Three lines, not identified, occur in Bessemer and spiegel only. Watts.
5540		5532
5506		5529 5542·3 and 5503·7. Carbon lines. Watts.
5488	More refrangible edge of band	5505·9 Fe. Fievez and Thalén
5481		
5470		
5462		5462 5462·3 " Fievez and Thalén
5455		5454 5454·7 " " "
5452		Three faint lines not identified, in Bessemer spectrum. Watts
5444	Centre of nebulous line or band	5443
	The more refrangible edge of a band appears here	5446 Fe. Fievez and Thalén
5437	Line	
5431	The more refrangible edge of a band	
5410		
5403		5405 Line. Watts 5404·9 Fe. Fievez and Thalén
5394	More refrangible edge of a band. Does not appear in the 2nd spectrum	5395 Line, strong. Watts 5396 Fe. Fievez and Thalén
5374	Line on a band	5371 Line, strong. Watts 5370·6 Fe. Fievez and Thalén
5366	Most refrangible edge of 2nd strong group of bands. There is apparently a line hereabouts which widens the edge of the band	5366·6 " " "
5333	Line indistinct on 1st spectrum, distinct on 2nd and 3rd spectra. It lies on a broad band on the 2nd spectrum, and the band extends to 5319	5327 Line, strong. Watts
5319	Edge of band, not degraded, very feeble	
5296	Doubtful line, very feeble	
5287	Very indistinct. Doubtful	5287·6 Fe. Fievez and Thalén
5270	Line strong. Coincident with solar line E	5269·5 " E. Fievez and Thalén
5246·5 5217	Two lines forming edges of a band. In 3rd spectrum only	
5195	Edge of band	5192 Edge of band. Watts
5184	Line coincident with solar line b^1	5183·8 Fe. Fievez and Thalén
5173	Short line, seen only at the base of flame. Not in the 1st spectrum	5170·9 " " "
5169	More refrangible edge of band, nearly coincident with solar line b^3	5167 In Bessemer spectrum. Not identified. Watts
	Also a line here, Fe	5167·1 Fe. Fievez and Thalén
5164	More refrangible edge of band	
5159	Edge of band. In 3rd spectrum only	5157 Edge of band. Watts

Plate 8.—Crewe—(continued).

λ.	Description of spectrum.	Remarks and lines for comparison.
5129·8	Edge of band, nearly coincident with a well-defined faint iron line, 5128·8	
5110	Feeble line	5109·2 Fe. Vogel and Thalén 5107 Line, not in MnO_2 spectrum. Watts
5084·4	Centre of faint broad line, probably double	
5037	More refrangible edge of band. Faint. Not in 3rd spectrum	
5019	More refrangible edge of weak band	5018 Edge of band. Watts. 5017·7 Fe. Vogel and Thalén
4969·5	,, ,, of slightly stronger band	
4947·5	Indication of sharp line, or edge of band . .	4943 Edge of band. Watts, also
4914·9	More refrangible edge of same band, not in 3rd spectrum	4945·7 Fe. Vogel and Thalén
4895·7	More refrangible edge of narrow band, not in 1st spectrum	4904 Edge of band. Watts
4861·8	More refrangible edge of narrow band. Coincident with solar line F. Measured on 2nd spectrum 4862. Not on 3rd spectrum	4862 ,, ,, ,,
		Combine to form one broad band
4838	More refrangible edge of band. Not in 3rd spectrum	4836 Edge of band. Watts 4838 Fe. Vogel and Thalén
4811·8	More refrangible edge of band. Not in 1st spectrum	
4808·2	Line. Not in 2nd or 3rd spectrum	4802 Line. Watts
4773	Edge of band	
4755	More refrangible edge of broad band. Seen more distinctly in 3rd spectrum	
4740	Edge of band about here	
4721 4709	Two short lines, visible only at base of flame. 4721 in 3rd spectrum only	4709·5 Fe. Vogel and Thalén
4701·5	Strong band	
4674	More refrangible edge of band	
4660	Visible only in 1st spectrum	
4637	More refrangible edge of band	
4623	Edge of band. Not in 2nd spectrum	
4606	Visible only in 3rd spectrum	4607 ,, ,, ,,
4584·5	Fairly strong line. Coincident with the more refrangible edge of a band	
4561·4	Edge of band. In 1st spectrum only	
		The continuous spectrum is strong over this region
4547	More refrangible edge of band. Feeble. Another measurement gave 4540. Doubtful	4547·3 Fe. Vogel and Thalén
4519	Or 4522. Faint line on a band about here. Doubtful	
4502	Line	
4504	Edge of band. More refrangible edge	
4496	Line	
4493	Short line. Visible only at the base of the flame on 1st spectrum	4493·8 ,, ,, ,,
4482·2	Strong line, also edge of strong band. Line coincident with a solar line	4481 Line. In Bessemer spectrum, not identified. Watts 4481·6 Fe. Vogel and Thalén
4469	Faint line, also 4468·8 the same line in another spectrum on a different plate. On 1st spectrum only. Plate 8.	4468·7 ,, ,, ,,
4466	A line closely adjacent to a solar line	4466 ,, ,, ,,

Plate 8.—Crewe—(continued).

λ.	Description of spectrum.	Remarks and lines for comparison.
4448·4	Strong line not in 1st spectrum	4447·2 Fe. Vogel and Thalén
4436·5	Faint sharp line.	
4430	Strong line	4432 Line not identified 4432·6 Fe. Vogel and Thalén. Watts
4414	Faint line. In 2nd spectrum only	4415·4 Line, in Bessemer. Not identified. Watts. 4414·3 Fe. Vogel and Thalén
4406	Very strong line. Not in 1st spectrum. Coincident with 4405 in solar spectrum	4404 Watts 4404·3 Fe. Vogel and Thalén
4385·4 4383·7	Pair of strong sharp lines. Both in solar spectrum, the former much the more strongly reversed	4383 Line, not identified. Watts 4383·0 Fe. Vogel and Thalén
4357	Edge of band.	
4351	,, ,,	
4326	Line, strong. Coincident with a solar line .	4325·3 Fe. Vogel and Thalén
4316	Line. In 2nd spectrum only	4314·6 ,, ,, ,,
4308	The same. In 2nd spectrum only. Coincident with solar line in G	4307·3 ,, ,, ,,
4272	The same. Coincident with a Solar line . .	4271·6 ,, ,, ,,
4253·5	Edge of band.	
4215·7	Line, strong. Coincident with a weak line in solar spectrum. In 2nd spectrum only	(4215·7 Possibly due to Mn)
4202	Very weak line. Not in 3rd spectrum . . .	(4201·6 ,, ,,)
4188	,, ,, Doubtful whether in 1st and 2nd spectra	4187·3 Fe. Vogel and Thalén
4178	Edge of band.	
4144 4132·2	Two weak lines, both rather diffuse . . . . In 1st spectrum only. Coincident with line in solar spectrum, 4132·2	4143·2 ,, ,, ,, 4131·3 ,, ,, ,,
4130	Edge of band.	
4071 4067 4063	Pair of strong sharp lines, with a feeble line between them. Coincident with lines in the solar spectrum; 4071 is visible in 1st spectrum only, 4067 in the 2nd spectrum only	4071 ,, ,, ,, 4063 ,, ,, ,,
4046 4042 4040·6	Group of three very strong lines, frequently appearing as two; 4046 is coincident with a solar line	4045·3 ,, ,, ,,
4034·8 4033·8 4032·7 4030·0	Strongest group of lines in the whole spectrum. Closely adjacent, and frequently appearing as one broad strong line. Coincident with a broad line in the solar spectrum	
4004	Weak line. Coincident with a solar line . .	4004·3 ,, ,, ,,
3967·7	,, ,, Coincident with the centre of the solar line H. On the 3rd spectrum only	3968·1 ,, ,, ,,
3929·8 3927·3	Pair of sharp, strong lines. Coincident with solar lines on the more refrangible side of K	Fe. Cornu and Lockyer ,, ,, ,,
3922 3920	Pair of sharp, strong lines. Coincident with two in solar spectrum	3922 ,, ,, ,, 3920 Fe. Cornu; 3919·4, Lockyer
3904·8	Sharp line	3905·9 Fe. Cornu 3903·3 Fe. Lockyer
3898·5 3895	Pair of sharp, strong lines. Coincident with solar lines	3898·4 Fe. Cornu. 3894·7 ,, ,,
3887	Very strong line. Coincident with a solar line	3886 ,, ,,
3878·5	,, ,, ,, ,,	3877·4 ,, ,,
3872 3866	Two weak lines. Coincident with solar lines	3871·3 ,, ,, 3865·5 ,, ,,

PLATE 8.—Crewe—(continued).

λ.	Description of spectrum.	Remarks and lines for comparison.
3860	Very strong line	From this point all lines are coincident with lines in the solar spectrum, and have been identified on ROWLAND'S first map.
3856	Strong line	
3850	Weak line	
3841	Strong line	
3834·3	,, ,,	
3826	Closely adjacent strong lines, the more refrangible being the stronger. Not in 3rd spectrum	
3824·5		
3820·5	Strong line. Coincident with solar line L	
3816	Two weak lines.	
3813		
3800	Line, fairly strong, broad	
3795	,, less strong	
3788·5	,, weak	
3781	,, in the 3rd spectrum only	
3767·5	A pair of lines	
3764		
3758·4	Very strong, evidently double. Lines closely adjacent Very strong group	
3749·4		
3746		
3743·5	Very feeble	
3737·4	Very closely adjacent strong line Very strong group	
3735·0		
3733·5		
3727	Weak line. Coincident with solar line M	
3722·8	Strong line Closely adjacent	
3720	Very strong line	
3709	Weak line. Not in 1st spectrum Group	
3707·7	,, ,, In 3rd spectrum only	
3705·5	Fairly strong. Sharp. Not in 1st spectrum	
3687·5	Weak line Group	
3685·2	Very weak, distinct line	
3680	Weak line	
3677·8	Fairly strong line	
3648	,, ,, Not in 1st spectrum	
3631·5	,, ,,	
3619	A pair, well defined, strong lines	
3609		
3587·2	Very weak line	
3585·5	,, ,, Not in 3rd spectrum	
3581·5	Strong, sharp line, in 1st spectrum only. Coincident with solar line N.	
3570	Two sharp, fairly strong lines	
3566		
3558·8	A very weak line	
3526·5	Weak, isolated line	
3498	Weak line	
3491	Fairly strong line. In 2nd spectrum only	
3477	Pair of lines weak.	
3475		
3466	Weak line.	
3441	Fairly strong line. Solar line O, 3439·2 . .	3441·07 Fe. KAYSER and RUNGE
3384	Very weak line	
3380·8	Fairly strong lines	

PLATE 6. CREWE. SENSITISED FOR THE RED RAYS.

1st spectrum.	2nd spectrum.	3rd spectrum	Description of spectrum.	Remarks and lines for comparison.
λ.	λ.	λ.		
..	6177	6173	Edge of band	6178. Edge of band, WATTS
..	6135	6135	Bands degraded towards the red	
..	6109	6101		6109. Conspicuous pair of red lines, WATTS
..	6042	6046		6097.
..	5991	6017		6012. 6006. Pair of faint lines, WATTS
..	5958	5959	Band degraded towards the red	
..	5917	5917	Line on band or edge	5917. WATTS
..	..	5893·7	Sodium	
..	5875	5875	Edge of band } Group of bands	5872. Faint line, WATTS
..	5831	5831	,, ,, ,,	
..	5794	5794	,, ,, ,,	5790. Strong, fine line, brightest edge of whole group, WATTS
5735	..	5736	Edge of band } Group of bands Strong, broad	
5719	..	..		
5670	..	..		
5625	..	..		
5622	..	..		
5590	5586	5586	,, ,, ,,	5580. Edge of band, WATTS
5556	..	..		
..	..	5476	Edge of band } Group of bands	
..	..	5457	,, ,, ,,	5453. WATTS
..	..	5439	,, ,, ,,	5443. ,,
..	5418·5	..		4533. ,,
5384	5384	5384	,, ,, ,,	
5370	5369	5369	,, ,, ,,	5370. ,,
5335·5	5335·5	5335·5	Line on band } Group of bands	This group resembles the same group as seen on the plates from DOWLAIS. The bands are more numerous than on other spectra taken at Crewe
5294	..	5303		
..	..	5270	,, ,, ,,	5269. ,,
..	..	5231	More refrangible edge of band	5229. ,,
..	..	5203	,, ,, ,,	
..	..	5198	,, ,, ,,	
..	..	5170	,, ,, ,, Sometimes appears as a line	5168. ,,

The bands on Plate 6, Crewe, are less well defined on spectrum 3, but are very well seen on spectrum 5; that is to say at the close of the fining stage. The temperature being high, and the carbon issuing from the mouth of the converter, all in the condition of carbon monoxide, there are no carbon bands or lines to obscure the manganese spectrum.

PLATE 2. SPECTRUM 3. CREWE.

λ.	
6196	Line seen at the edge of a band. Spectrum 4.
6131 6077	Band.
6020	Line on band.
5952 5893	Band degraded towards the red.

Plate 9. Spectra 4 and 5.

4th spectrum.	5th spectrum.	Description of spectrum.	Remarks and lines for comparison.
λ.	λ.		
5876	5872	Edge of band or line upon a band	5872. Faint line, Watts
5830	5831	Least refrangible edge of a band degraded towards the red. Appears like a line on 4th spectrum, in the upper part of the flame and like a band at its base	
5794	5794	More refrangible edge of a band, appearing like a broad line at the tip of the flame and as a band at its base in 4th spectrum, the band not perceptibly degraded. It is degraded towards the red in the 5th and appears as the more refrangible edge of a band throughout	5790. Strong fine line, brightest edge of whole group, Watts
5700	..	Less refrangible edge of a band in the most intense group. Very strong but obscured, degraded towards the red	5705. Fine line, Watts
5650	5650	More refrangible edge of a band, degraded, very strong, broad	5644. Brightest edge of band, Watts
5621	5621	More refrangible edge of band, degraded towards the red, very strong	
5585	5585	The same, strongest and most refrangible of this series	5580. Edge of band, Watts
5546	5546	More refrangible edge of the strongest band of this group, degraded towards the red, broad	5547. One of a group of three lines, Watts
5488	..	More refrangible edge of a band, strong	
5439	5439	” ” ” ”	5443. Watts
5424	..	” ” ” ” broad	
5384	..	” ” of very strong band. Degraded towards the red. Conspicuous in the group with 5546	5391. Edge of band, Watts
..	5370	More refrangible edge of band terminating this group in 5th spectrum. Strong	5371. Strong line, Watts
5348	..	More refrangible edge of a band overlapped by 5384. Not degraded	
5338	5337	Line on band of continuous rays	
5270	5270	Line coincident with solar line E	5269. ” ” ”
5170	5170	Line nearly coincident with b^3 and b^4 in solar spectrum	5167. Line. Watts

Lines of the Alkali Metals and of Hydrogen, observed in the Spectrum of the Bessemer Flame.

Hydrogen. λ.		
6564	Plate 2, 3rd spectrum. Reversed	Coincident with the solar line C.
4861·8	Plate 8, 1st and 2nd spectra only. Appears as the edge of a band	
Lithium.		
6707	Plate 2, 3rd spectrum	
4132		
Sodium.		
5893	On every plate. In one or two spectra the two lines are separated. Generally, however, very broad	Coincident with D.
Potassium.		
7697 7663	Observed with eye	
4045 4042	On every plate strong	4045 4042 Liveing and Dewar

Lines of Carbon or Edges of Carbon Bands and of Carbon Monoxide, observed in the Spectra of the Bessemer Flame.

Carbon.

Bessemer flame.	Description of spectrum.	Carbon bands. (Flame Spectra. Part I.)	Remarks and lines for comparison.
λ.		λ.	
5655	Indistinct, more refrangible edge of a band. Not distinguishable in 3rd spectrum	5659 to 5627	
5634	An intense band overlying other bands . .	5634·7	Carbon, Watts
5629	. . . .	5629	Lecocq de Boisbaudran
5625	Edge of band distinct, strong	5627	
		5627·3	Fievez
5611	. . . .	5611	
5588	Edge of band terminating the first strong group. Not in 2nd spectrum	5585·5	Edge of band, Watts
		5581	Lecocq de Boisbaudran
		5580	Edge of band, Watts
5579	Edge of band. Another spectrum . . .	5577	
5540	. . . .	5542·3	
5506	. . . .	5503·7	
5488	Edge of band	5492	Also Fe 5488·4, Kayser and Runge
5470	. . . .	5473	
5444	Centre of a nebulous line, or a band . . .	5446	
	The more refrangible edge of a band also appears here	5443	One of these faint lines not identified, Watts
5195	Edge of band	5194	Band
5169	,, ,, ...	5170	
5084·4	Centre of faint broad line, or a band . . .	5086	
4974·5	Indication of sharp line, or band	4952	
4895·7	More refrangible edge (?) of a narrow band. Not in 1st spectrum	4899	Also 4896, Mn.
4773	. . . .	4774	
4674	Edge of a band. Visible only in 1st spectrum	4672	
4466	Line closely adjacent to a solar line . . .	4462	
4406	Very strong line. Not in 1st spectrum . .	4405	Also Fe 4405, Kayser and Runge
4357	Edge of band	4364	
4351	,, ,, ...	4350	
4253·5	,, ,, ...	4252	
4215·7	Line strong, coincident with a weak line in in the solar spectrum. In the 2nd spectrum only	4215	

The Carbon Monoxide Spectrum observed in the Bessemer Flame.

Bessemer flame.	Description of spectrum.	Carbon Monoxide Spectrum. (Flame Spectra. Part I.)	Remarks.
λ.		λ.	
5037	More refrangible edge of a band. Not in 1st spectrum	5037	
4969·5	More refrangible edge of stronger band	4970·5	
4947·5	Indication of sharp line, or band	4945	
4637	Edge of band	4640	The continuous spectrum of carbon monoxide extends in this region from 4755 to 4405
4606	Visible only in 3rd spectrum	4589	
4584·5	Fairly strong line, coincident with the more refrangible edge of a band		
4448	Strong line. Not in 1st spectrum	4446	Also Fe 4447·2
4188	Very weak line. Doubtful whether in 1st and 2nd spectra	4183	

Bands and Lines of Manganese observed in the Spectra of the Bessemer Flame.

Bessemer flame.	Description of spectrum.	Manganese spectrum. (Flame Spectra. Part II.)	Remarks and lines for comparison.
λ.		λ.	
6635			
6196			
5872		5873	
5865		5865	
5855		5855	5858, Lecocq de Boisbaudran
5787		5800	
5767		5764	
5718		5712	
5625		5622	
5608			
5595		5591	Edge of band, hazy
5588			
5556		5556	
5462		5465	
5444		5445	
5437		5438	
5403		5402	
5394		5391	5393·6, Thalén
5374	Line on a band	5370·5	5371, Watts
5366	Edge of band	5364	
5333	Line, indistinct on 1st spectrum, distinct on 2nd and 3rd. It lies on a broad band on the 2nd spectrum, and the band extends to 5319	5338	
5319	Edge of band. Not degraded; very feeble	5315	
5270		5270	
5195	Edge of band	5199	Carbon band here also
5169	More refrangible edge of band	5167	
5159	Edge of band; in 3rd spectrum only	5157	
5019	More refrangible edge of faint band	5018	
4895·7	„ „ „ narrow band; not in 1st spectrum	4896	

BANDS and Lines of Manganese observed in the Spectra of the Bessemer Flame—(continued).

Bessemer flame.	Description of spectrum.	Manganese spectrum. (Flame Spectra. Part II.)	Remarks and lines for comparison.
λ.		λ.	
4773	Edge of band	4776·5 to 4770	Very weak band in MnO_2 spectrum. See also Carbon
4755	More refrangible edge of broad band. More distinctly seen in 3rd spectrum	4749·5	
4701·5	Strong band	4696	See Carbon
4660	Band. Visible only in 1st spectrum	4656	
4502	Pair of fairly strong lines; also more refrangible edge of band	4503	
4496		4501	
4493	Short line, visible only at base of the flame. 1st spectrum	4491	
4469	Faint line. 1st spectrum	4470·5	
4436·5	Faint sharp line	4436·5	
4414	Faint line	4414·2	
4406	Very strong line	4403	MnO_2, edge of band. Also, see Carbon, 4405
4326	Line, strong	4325·3	THALÉN
4272	Line	4271·6	,,
4253·5	Edge of band	4252	See Carbon. See also Carbon, 4255
4130	,, ,,	4130	
4067		4065	
4063		4064	
4040·6	Very strong line	4040	
4034·8		4034·9	4036·5 Some of these wave-lengths have been adopted from WATTS' Index of Spectra
4033·8	Strongest group of lines in the whole spectrum. They appear as a band degraded towards the less rafrangible rays in MnO_2	4033·8	4033·8 Reversed in the arc
4032·7		4032·7	4032
4030		4029·9	4029·5
3895	Strong, coincident with a solar line	3894	
3887	Very strong line, coincident with a solar line	3886	
3878·5	,, ,, ,, ,, ,,	3878	
3872	Two weak lines, coincident with two solar lines	3874	
3866		3866	
	From this point all lines in the Bessemer flame spectrum are coincident with solar lines.		
3860	Very strong line	3860	
3834	Strong line	3835	
3824·5		3824	
3727	Weak line, coincident with the solar line M	3728	
3722·8	Strong line	3721	
3619	A pair of well-defined fairly strong lines	3621	
3609		3607·5	
3587·2	Very weak line	3589	
3585·5	,, ,, ,, not in 3rd spectrum	3587	
3581·5	Strong sharp line, in 1st spectrum only, coincident with solar line N	3578	
3570	Two sharp fairly strong lines	3571	
3566		3568	
3558·8	A very weak line	3559·5	
3498	Weak line	3498	
3491	Fairly strong line, in 2nd spectrum only	3490·5	
3477	Pair of weak lines	3476	
3475		3473·5	
3441	Weak line	3442	

LINES in the Spectrum of the Bessemer Flame, identified with Lines in the Solar Spectrum, and with Iron Lines.

Column I. Lines in Bessemer flame identified with lines in the solar spectrum. The black figures indicate the strongest and most prominent lines.

,, II. Lines identified on KAYSER and RUNGE's photographs of the arc spectrum of iron.

,, III. The spectrum of iron obtained from steel by the oxyhydrogen flame.

,, IV. The oxyhydrogen flame spectrum of pure ferric oxide.

	I. Bessemer and solar lines.	II. Arc lines. Iron.	III. Steel.	IV. Fe_2O_3.	Remarks.
D	5893·7				
E	5270·6	5270·43 E			
		5269·65			
b^3	5170	5171·71			
	5042	5041·85			
	4502				Lines strong and well defined
	4496·5	4494·67			
	4486	4485·77			
		4484·36			
	4448·4	4447·85			
	4436·6	4435·27			
	4405	4404·88			
G	4385·4				Lines all strong and well defined. Continuous spectrum of carbonic oxide very strong, somewhat obscures the metallic lines
	4383·7	4383·7			
	4368·4	4367·68			
	4326	4325·92	4326		
	4308	4307·96	4308		
	4272	4271·93	4272		
	4215·7	4216·28			
	4202	4202·15			
	4188	4187·92			
	4144	4143·96			
	4132	4132·15			
	4072	4071·79	4072		Lines well defined
	4063·8	4063·63	4063·8		
	4046	4045·9	4046		
	4044·8	4044·69			
	4044·2	4044·0			
	4041·7	4041·44			
	4036	4035·76			The strongest lines in the spectrum dividing the visible from the ultra-violet rays
	4034·8	4034·59			
	4033·8	4033·16			
	4031	4030·84			
	4005·5	4005·33			
	3969·34	3969·34			
	3966·8	3966·7			
	3929·8	3930·37	3929·8	3929·8	
	3927·3	3928·05			Strongest part of the spectrum. Nearly all iron lines, many of which are very prominent. Continuous spectrum not too strong to admit the lines being well seen
	3922	3923·0	3922	3922	
	3920	3920·36			
	3904·8	3903·06	3904·8	3904·8	
	3898·5	3899·8	3898·5	3898·5	
	3895·0	3895·75			

LINES in the Spectrum of the Bessemer Flame, identified with Lines in the Solar Spectrum, and with Iron Lines (continued).

	I. Bessemer and solar lines.	II. Arc lines. Iron.	III. Steel.	IV. Fe_2O_3.	Remarks.
	3886·5	3886·38	3886·5	3886·5	Strongest part of the spectrum. Nearly all iron lines, many of which are very prominent. Continuous spectrum not too strong to admit of the lines being well seen
	3878·5	3878·12			
	3872	3872·61			
	3860	3860·03	3860	3860	
	3857	3856·49	3857	3857	
	3850	3850·11			
	3841	3841·19	3841		
		3840·58			
	3834·3	3834·37	3834		
	3826	3826·04	3826	3826	
	3824·5	3824·58	3824·5	3824·5	
L	**3820·5**	3820·56			
	3816·5	3815·97			
	3813·0	3813·12			
	3800	3799·68			
	3795	3795·13			
	3788·2	3788·01			
	3767·5	3767·31	3767·5		
	3764·0	3763·9	3764		
	3758·4	3758·36	3758·4	3758·4	
	3749·5	3749·61			
	3748·5	3748·39	3748·5	3748·5	
	3745·9	3745·67	3745·9	3745·9	
	3743·5	3743·45			
	3737·4	3737·27	3737·4	3737·4	
	3735·0	3735·00	3735	3735	
	3733·5	3733·46			
M	**3727·8**	3727·78 3727·13	3727·8		
	3722·8	3722·69	3722·8	3722·8	Well defined strong lines
	3720·0	3720·07	3720		
	3709	3709·37			
	3707·7	3708·03			
	3705·5	3705·70	3705·5	3705·5	
	3687·5	3687·58	3687·5		
	3682·3	3682·35	3682·3	3682·3	
	3680	3680·03			
	3648	3647·99	3648	3648	Well defined but weak lines
	3631·5	3631·62	3631·5	3631·5	
	3619	3618·92			
	3609	3608·99	3609		
	3585·5	3585·43			
N	3581·5	3581·32	3581·5	3581·5	
	3570	3570·23	3570	3570	
	3566	3565·5	3566		
	3526·5	3526·51			
	3498	3497·92			
	3491	3490·65	3491	3491	
	3477	3476·75			
	3475	3475·52	3475	3475	
	3466	3465·95	3465·95	3465·95	
O	3441	3441·07	3441	3441	
	3380·8	3380·17			
P	3361·5	(3361·30)			In Bessemer and solar spectra

The Constitution of the Bessemer Spectrum.

It will be readily understood from the previous investigations of the flame-spectra of iron, manganese, spiegel-eisen, ferro-manganese, silico-spiegel, tool-steel, pure manganic oxide, carbon, carbonic oxide, and cyanogen, that the Bessemer-flame spectrum is not characterised especially by the bands of carbon, as would be the case according to the views of ROSCOE, nor of carbonic oxide according to LIELEGG and KUPELWIESER, nor does it belong entirely to manganese as indicated by the observations of BRUNNER, VON LICHTENFELS, and WEDDING; furthermore, it cannot be attributed chiefly to manganic oxide, as stated by WATTS. It is, in fact, a complex spectrum, in which the bands of metallic manganese, carbon, carbonic oxide, and cyanogen, possibly also of manganic oxide, are superposed; and the lines of iron and manganese occur with those of other elements, such as hydrogen, lithium, potassium, and sodium. The hydrogen line (C in the solar spectrum) was photographed only once, and then during a snowstorm, when it appeared completely reversed. No absorption bands were at any time visible when observations were made upon the flame only. No nitrogen bands were seen. No bands belonging to calcium and magnesium oxides were visible, nor lines of these elements. No cobalt, nickel, copper, nor chromium were detected. The lines beyond the solar line K, which had hitherto not been examined, are nearly all lines of iron, as mapped by CORNU and ROWLAND in the solar spectrum, and observed in the arc-spectrum of iron photographed by KAYSER and RUNGE.

Cause of the Non-appearance of Lines at the Commencement and Termination of the "Blow."

SILLIMAN detected thirty-three lines in the Bessemer-spectrum; some of LIELEGG'S lines were not observed, and others which he did not record were found. Dark bands were observed, crossed by bright lines; and it is suggested that the brilliant lines tend to make a weak continuous spectrum appear discontinuous, the dark bands being merely intervals between the bright ones. The iron spectrum had not been satisfactorily identified. According to SILLIMAN'S statement, "the Bessemer-spectrum contains yet many mysteries to be solved, among which is the cause of the non-appearance of the lines of the spectrum at the beginning and termination of the 'blow.'"

WEDDING accounted for the absence of the spectrum at the beginning and termination of the "blow" by the absolute quantity of the substance volatilized being at these times too small to produce a spectrum. ("Das Spectrum der Bessemer flamme." 'Zeitschrift für das Berg- Hütten- und Salinen-wesen,' vol. 27, p. 117, 1869.) He based his view upon the fact, recognized by SIMMLER, that a much larger quantity of manganese is required to obtain a recognisable reaction in the flame than that which can be detected by the well-known blowpipe test with carbonate of soda. In the

Bunsen flame, $\frac{1}{83}$rd of a milligramme of manganese can be detected (Simmler); but the quantity of alkalies is much smaller—as, for instance, $\frac{1}{3000}$th of a milligramme of potassium, $\frac{1}{600,000}$th of lithium, and $\frac{1}{14,000,000}$th of sodium (Kirchhof). The flame spectrum of manganese is almost entirely a banded spectrum, the peculiarities of which had not been investigated at that time.

Silliman had urged against this view of Wedding:—1st. If the disappearance of the manganese lines in the Bessemer spectrum be owing to the diminution of the quantity of manganese, we should infer that these lines would gradually grow more indistinct, and then fade away; but the fact is the contrary—the manganese spectrum increases in brilliancy from its first appearance, and is more intense just before being swept away than at any other time. The analysis of the fume which appears when the flame ceases, proves that a considerable quantity of manganese is still volatilized; and it is notable that in manganiferous iron this quantity increases towards the close of the "blow." 2nd. It would be more difficult to account by this theory for the non-appearance of the sodium line at the beginning of the "blow," as sodium then, in all probability, exists in the issuing gas in sufficient quantity to produce its spectrum at a high temperature, as it is only by special precautions that we can keep it out of any flame. 3rd. A still greater difficulty would arise in applying this theory to the spectra of sodium and lithium at the close of the "blow." As has been stated, these lines sometimes disappear at the moment of complete decarburization, and sometimes remain. In the former case to say that the sodium had been exhausted would not be in accordance with what we know of that element.

Wedding based his explanation of the non-appearance of the manganese lines upon the analysis made by Brunner. It was found that the manganese contained in the iron fell from 3·46 per cent. in the pig to 1·645, 0·429, and finally to 0·113 per cent. in the decarburized product; and that the manganous oxide in the slag first increased from 37·00 to 37·90 per cent., and then sank to 32·23 per cent.; and, furthermore, that a certain amount of manganese is to be found in the fume.

Silliman states that since the manganese contained in the pig iron decreases continuously, and that contained in the slag after the termination of the boiling period also decreases, a considerable volatilization of this body is probable, just at the time when the spectrum is best developed. Wedding found from Brunner's analysis that some of the manganese is volatilized from the slag, and it was further considered that the manganese spectrum during the entire process cannot be due wholly to the volatilization of manganese directly from the iron; for while the amount eliminated from the iron grows continually less, the manganese spectrum grows brighter. If there were a sufficiently large quantity of carbonic oxide flame to render the escaping gases glowing, it is evident they would not issue from the converter as dark smoke, but as incandescent vapour, having its characteristic spectrum. The lack of sufficient flame may therefore account for the disappearance of the manganese spectrum.

Against Silliman's criticism of Wedding's arguments it may be urged that, because the proportion of manganese decreases in the "pig," and that contained in the slag after the termination of the "boil" also decreases, it does not necessarily follow that the actual quantity of manganese in the slag is diminished. Data are wanting which would enable us to decide how much manganese is volatilized, since we do not know the absolute quantity of slag and iron.

BRUNNER's analyses do not appear to me to prove that the absolute quantity of manganese in the slag diminishes or increases during the "boil," since manganese is not the sole basic constituent of the slag. This question was considered by MARSHALL WATTS who, in experiments both at Crewe and at Barrow, always observed a difference between the ordinary Bessemer spectrum as seen at Crewe and that of spiegel-eisen. The difference, which consisted in a relative intensity of the lines, was so great that it was not at first perceived that the spectra were in any way the same. At Barrow this difference in the spectrum was not seen, the spectrum of spiegel-eisen being identical with that of Bessemer metal, only more intense. The ordinary Bessemer spectrum at Barrow was identical with the spiegel spectrum at Crewe. The difference between the Barrow and the Crewe spectra was attributed by WATTS simply to a difference in temperature. It was stated, however, that it might have been connected with a difference in composition of the metal operated upon. Experiments made on the temperature of the flame showed that at the commencement it was below 1300° C., but it gradually rose without reaching 2000° C.

From a study of my photographs it appears certain that the whole phenomenon is primarily due to rise of temperature, which takes place rapidly and continuously during the "boil," while at the same time an increasing quantity of carbonic oxide escapes from the converter. The bath of metal is first heated by the oxidation of the manganese and silicon. Such oxidation produces an enormous amount of heat; first, because the heat of combustion of these elements is very high; secondly, because the products of combustion are solid, or at high temperatures liquid, and carry none of the heat away. This appears to have been first recognised by Lieutenant DUTTON, U.S.A., in 1871. ('Chem. News.,' vol. 23, p. 51.) Then the carbon burns and yields a large amount of heat to the metal, the hot metal heats the blast which passes through it, and so increases the rapidity of combustion of the carbon, which serves again to raise the temperature of the metal. The gaseous contents of the converter are carbonic oxide and nitrogen, and within this atmosphere the manganese and iron are vaporized, but not oxidized.

It may be easily understood that the temperature continues to rise until near the termination of the "boil," because the temperature of the bath of metal increases, and consequently the temperature of the blast as it escapes from the metal increases, so that the temperature of the combustion of the carbon and also of the carbonic oxide is higher. We are, in fact, dealing with combustion under similar conditions to those in a Siemens furnace on the regenerative principle.

That the spectrum remains at its brightest until the end of the "fining stage," I conclude, from the evidence of my photographs, is certainly not the case. Even the eye can detect a waning in the brilliancy of the spectrum.

See Bessemer photographs 8 and 10, taken at Dowlais; of the six spectra on Plate 8 the fifth is by far the strongest. The fourth and sixth are much the same as regards manganese, but the sixth is much stronger in iron lines, and also has a stronger continuous spectrum.

On Plate 10 there are nine spectra, each of which received an exposure of half a minute, the first and last of these are the weakest.

In confirmation of this the detailed statement may be quoted which refers to these particular plates.

April 6th, 1893, old Bessemer plant.—Dowlais, grey pig iron, containing not less than 2 per cent. of silicon and $3\frac{1}{2}$ to $3\frac{3}{4}$ per cent. carbon, was being blown for tin-plate iron in quantities of 10 tons. The position of the instrument was just about 4 feet above the mouth of the converter and about six feet away from it. The blast was turned on at 12 o'clock until 12.5 P.M.; the flame contained nothing but the continuous carbonic oxide spectrum, with the usual alkali metals, but at 12.5 P.M. the manganese bands began to flash out. The first exposure was at $12.7\frac{1}{2}$ P.M. until $12.8\frac{1}{2}$ P.M.

	h.	m.	s.		h.	m.	s.
2nd exposure from	12	8	30	to	12	9	40
3rd ,, ,, ...	12	9	40	,,	12	10	10
4th ,, ,, ...	12	10	10	,,	12	11	10
5th ,, ,, ...	12	11	10	,,	12	14	10
6th ,, ,, ...	12	15	0	,,	12	17	0

The flame was perfectly transparent at the highest temperatures, and it was possible to look right into the converter and see the fluid slag thrown up against the mouth and drop back into the vessel.

This fact is to be noted, the fourth spectrum had an exposure of exactly a minute, while the sixth had two minutes; as regards the manganese bands the spectra are much alike, but in carbonic oxide and in iron lines the sixth is much the stronger spectrum. This shows that the quantity of manganese vapour was decreasing, but the quantity of iron vapour was increasing.

Though the fifth spectrum received an exposure half as long again as the sixth, the spectrum is much more than twice as strong.

PLATE 10. Dowlais. April 6th, 1893.

The same pig iron blown for tin-plate metal as before.

"Blow" commenced at 12.45 P.M.
"Blow" interrupted at 12.49 ,,
Blowing re-commenced at 12.55 P.M.

	h.	m.	s.		h.	m.	s.
1st exposure at	12	50	30	to	12	59	30
2nd ,, ,,	12	59	30	,,	1	0	30
3rd ,, ,,	1	0	30	,,	1	1	30
4th ,, ,,	1	1	30	,,	1	2	30
5th ,, ,,	1	2	30	,,	1	3	30
6th ,, ,,	1	3	30	,,	1	4	30
7th ,, ,,	1	4	30	,,	1	5	30
8th ,, ,,	1	5	30	,,	1	6	30
9th ,, ,,	1	6	30	,,	1	7	30
10th ,, ,,	1	7	30	,,	1	8	30
11th ,, ,,	1	8	30	,,	1	9	0

The first and last spectra are exceedingly feeble, showing scarcely any spectrum. It is true that No. 11 received an exposure of only half a minute, as against one minute for all others, but this would not account for the very feeble spectrum as compared with the very strong one of No. 10, and the much stronger No. 9.

It is evident that the manganese bands are disappearing and the iron lines are becoming more prominent. As soon as all the carbon is burnt the temperature must fall very rapidly, because the principal combustible left is the iron, and its heat of combustion is comparatively low; the high temperature of the metal would therefore not be long maintained, and the blast would very soon, under these conditions, cool the metal, so as to solidify it, as we know is really the case when "skulls" are formed.

The metallic vapour within the converter, as soon as the atmosphere ceased to be composed of carbonic oxide in excess, would be converted into oxides and produce fume.

GREINER has described the manufacture and uses of a Bessemer steel from pig iron containing phosphorus and a large quantity of manganese.*

The following figures show the composition of the pig iron used and the steel obtained from it at Zwickau.

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* 'Revue Universelle,' vol. 35, p. 623, 1874. 'DINGLER'S Polytech. Journ.,' vol. 217, p. 33, 1875, and 'Journ. Chem. Soc.,' vol. 1, p. 454, 1876.

Pig iron.		Steel.	
Si	2·5 per cent.	Si	0·4 to 0·7 per cent.
S	0·04 ,,	S	0·06 per cent.
P	0·1 to 0·12 per cent.	P	0·1 to 0·15 per cent.
Mn	2·6 ,, 4·0 ,,	Mn	0·4 ,, 0·7 ,,
C	3·5 per cent.	C	0·15 per cent.

The indication of the close of the process differs from that in ordinary work, for whereas the spectroscope usually gives distinct indications during the "fining stage," with manganiferous pig it is much more difficult to make use of it to advantage.

The excessively brilliant flame due to the combustion of manganese vapour necessitates the use of dark blue glasses to protect the eyesight of the operator. When the metal is decarburized a thick smoke of brown oxides rises out of the bath, and finally becomes so dense that it hides all other indications. But before this moment has arrived the lines in the blue disappear, the bands in the green grow weaker and then disappear, while those in the yellow become weaker. When all the bands have vanished the spectrum becomes continuous.

The blast is continued for a minute or two longer to decarburize the metal as completely as possible, and a sample of slag and metal is removed from the converter by thrusting a wrought-iron bar into the bath; from the appearance of these samples the nature of the metal is ascertained.

This brown smoke of oxides has been noticed by Dr. MÜLLER, of Osnabrück ('Le Génie Civil,' vol. 1, p. 25, 1880), when the converter is inclined so that some air passes over the surface of the bath of metal; it is, therefore, due to oxidation.

I have observed such fume to be produced in enormous volumes when the charge has become too hot, and the converter is turned down during the "boil," so that the blast instead of passing through the molten metal passes over its surface and sweeps out the vapours of iron and manganese. Clouds of foxy-red smoke produced in this manner I have seen rise to a height estimated to be at least 200, and even 300 feet. The smoke is composed of little spherular particles containing oxides of iron and manganese.

There can be no doubt that WEDDING was, in the main, correct in considering that the non-appearance of the lines of manganese at the commencement and termination of the "blow" is owing to the fact that the quantity of material volatilised at these periods is insufficient for the production of a spectrum; but it may also be due, at the close of the process, to the oxidising atmosphere within the converter.

The spectroscopic phenomena of the blow are undoubtedly determined by the chemical composition of the gaseous contents of the converter and of the bath of metal, the temperature of the metal, and of the issuing gases. The effect of rise of temperature is to increase the volatilisation of manganese and iron.

Diagram I.

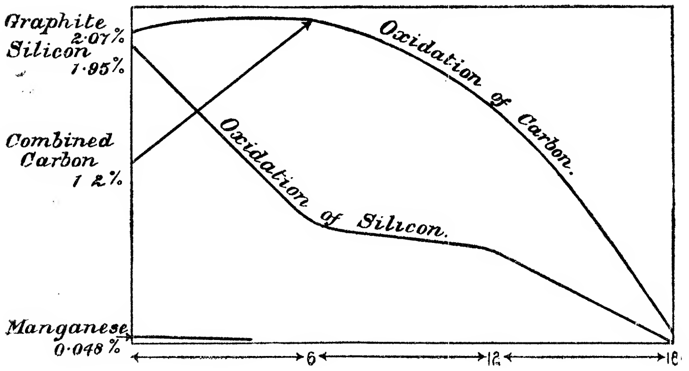


Diagram II.

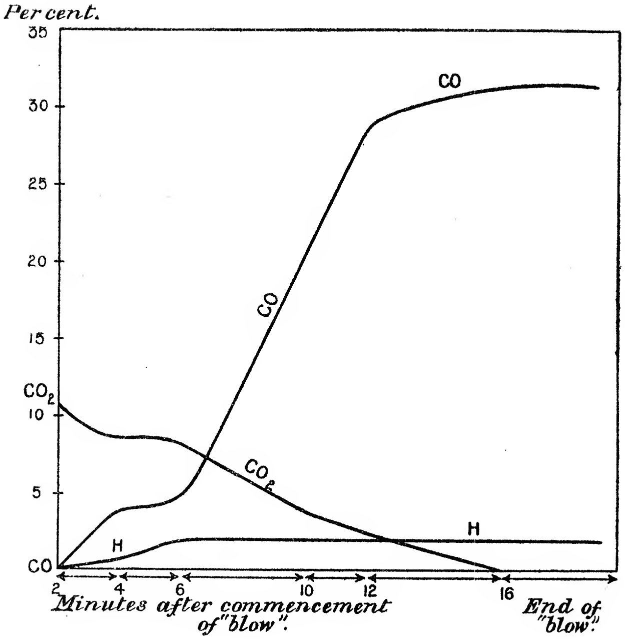
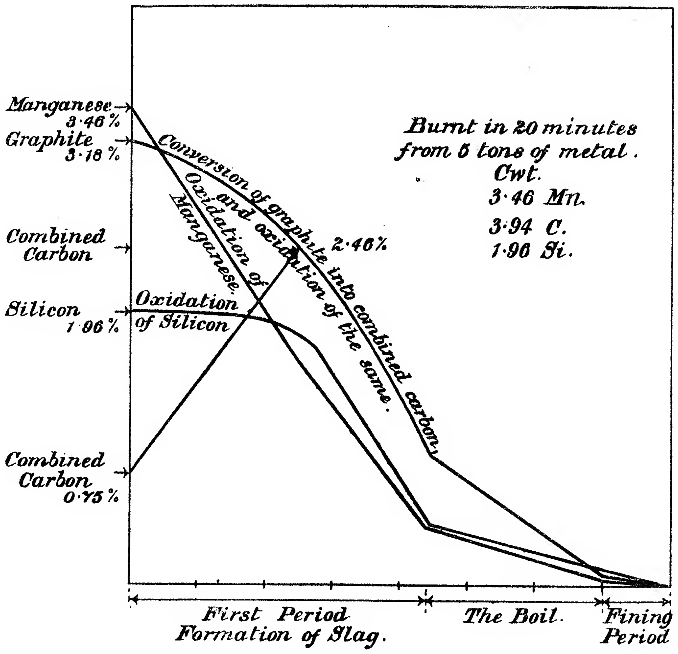


Diagram III.



Diagrams I. and II. are drawn from analytical data given by G. J. Snelus, 'Chemical News,' vol. 24, p. 159, 1871. Diagram III. from analyses quoted by Brunner, 'Oesterreichische Zeitschrift für Berg- und Hütten-wesen,' p. 227, 1863.

An explanation of this will be facilitated by reference to three series of curves. The first is reduced from the analyses of Mr. G. J. SNELUS, F.R.S., who gave the original composition of pig iron blown, and of the metal in the converter at different stages in the process; the second series is from the analyses made by the same chemist, of the gas issuing from the converter at different periods. The third series of curves is drawn from the analyses of metal taken from the commencement until the termination of the "blow" as quoted by KUPELWIESER. The pig iron in the latter case was highly manganiferous.

It will be seen from Diagram I., that the pig-iron contains very little manganese, and that this is oxidised immediately during the first six minutes. A small proportion of combined carbon is oxidised at the same time. The larger proportion, however, of this element is in the form of graphite, and this is converted into combined carbon. The combined carbon is then oxidised, and the oxidation proceeds with increasing rapidity. The silicon at the same time also oxidises, and the oxidation of the two elements proceeds together rapidly during the "boil," until during the "fining stage" there is little of either left. Comparing these results with the composition of the issuing gas, what do we find? First in the slag-forming stage, when the lines of the alkali metals are not yet visible in the spectrum, the carbon oxidised is all converted into carbon dioxide. But the temperature rises, and there is a production of carbonic oxide, a gas which, according to Sir I. LOWTHIAN BELL, has a greater stability in presence of iron at elevated temperatures. At this period the lines of the alkali metals are seen. The gases of the converter, under such conditions as exist during the "boil," are those of a reducing atmosphere. Oxidation of combined carbon to carbonic oxide then continues until near the close of the "fining stage," and it will be noticed that oxidation proceeds with increased activity. If we consider that the temperature of the metal at the commencement of the "blow" is no higher than that of the melting point of cast iron, that free oxygen passes through it and carbon dioxide is evolved, there can be no doubt that the temperature is insufficient to volatilise manganese if it be present, and, therefore, no spectrum of this element is visible.

When manganese cannot be vaporised, iron certainly cannot. Even the alkali metals are not carried out of the converter for some five or six minutes. When the gases are largely composed of carbonic oxide, and a higher temperature prevails, the alkali metals are volatilised, and the principal lines of sodium and potassium are observed during different periods up till the termination of the "blow." Why the red and violet lines of potassium are not visible is, no doubt, owing to the overpowering brilliancy of the other portions of the spectrum, and not because they are absent. The best evidence of this is, that on plates specially sensitised, the red line appears, and in every case the violet lines have been photographed.

The curves reduced from KUPELWIESER'S analyses are very different in detail, though the same in general effect.

The leading difference is owing to the composition of the metal being that of a highly manganiferous iron, containing much carbon and silicon.

Here we have manganese oxidised from the first, but at a low temperature; the silicon is also oxidised, and a slag is formed from the resulting materials. The combined carbon, the silicon, and the manganese, are oxidised together during the "boil," when the temperature rapidly rises. The effect of this is to volatilise both manganese and iron, and the gas of the converter constituting a reducing atmosphere at a high temperature, carries the metals out of the converter, where they are burnt in air along with the carbonic oxide. Towards the close of the "fining stage" the manganese in the fume is reduced in quantity and the iron is increased, so that the lines of the one give place to those of the other metal.

Suddenly the iron spectrum also becomes enfeebled, and the "blow" is stopped. Without doubt we have, at this point, a very rapid diminution of temperature, because the only combustible material left is iron, and its heat of combination is comparatively small.

The Bessemer flame is not the result of combustible gases and vapours being mixed with oxygen and burning within the converter, and thus, in a state of combustion, issuing into the air; but on the contrary, it is a flame of carbonic oxide at an exceedingly high temperature burning outside the converter in a cold atmosphere.

The Temperature of the Bessemer Metal and of the Flame.

Various attempts were made by WATTS to determine the temperature of the flame, and he concluded that, though it was above the melting-point of gold, it was below that of platinum.

According to some recent measurements made by LE CHATELIER ('Comptes Rendus,' vol. 114, p. 670), the temperature in the Bessemer converter during the "boil" is 1330° C., at the finish 1580°; while the steel in the ladle is at 1640° C. The scale of temperatures adopted was that of VIOLLE, viz.:—

Melting-point of gold	1045° C.
" " palladium	1500° C.
" " platinum	1775° C.

We have no measure of the temperature at the hottest period of the "boil," and unless the metal in the converter is cooled during the last minute of the blow, which my photographs clearly indicate, it is difficult to understand how its temperature could be raised by the addition of the cooler spiegel-eisen at the conclusion of the process of decarburization, and the still cooler ferro-manganese which is added while at only a red-heat. The rise of temperature at this period could be accounted for by the short "after-blow" of a few seconds, which is intended merely to mix the two kinds of metal, but in no case could it exceed the temperature of the "boil," or that moment when the spectrum is most intense.

It must be remembered that the composition of the pig iron used, and the more or less rapid rate at which it is blown, undoubtedly influence the temperature. The greater the mass of material operated upon, the greater will be the rise in temperature. For instance, a greater heat evolution and a higher temperature would result from the combustion of 10 cwt. of silicon in 12 tons of pig iron during a blow of 12 minutes, than from 1 cwt. of silicon in 5 tons of pig iron blown for 20 minutes. There is one significant fact to be observed in the spectra of the flame photographed during the "boil" and the "finishing stage" which bears upon the temperature of the metal. When the oxyhydrogen-flame spectra of manganese, manganic oxide, iron, and ferric oxide are photographed, the number of the lines and bands in the spectra are not more numerous than with a Bessemer flame spectrum of only one half minute's exposure, though the above spectra may have received any exposure from 30 to 80 minutes.

Marshall Watts observed ('Phil. Mag.,' 1870) that the sodium lines 5681 and 5687 may be employed as an index of temperature, since they are present in the spectrum of any flame containing sodium the temperature of which is hot enough to melt platinum, but do not appear at lower temperatures. The Bessemer flame does not show this double line, but only the D lines; neither does it show the lithium orange line, which appears at a somewhat lower temperature.

We cannot conclude from this that the flame is not hot enough to produce these lines, because in such a case we have to deal, not only with the temperature, but the quantity of material present, and the relative brilliancy and consequent visibility of the two pairs of sodium lines.

The proportion of sodium in the Bessemer flame is evidently very small, from the narrowness and want of intensity of the D lines, and the fact that they were not seen reversed in any spectrum. Hence, though the temperature may be high enough, the quantity of material present is not sufficiently large to yield the lines 5681 and 5687.

The quantitative relations of the different lines have really not been investigated in flame-spectra, except and alone so far as they apply to total extinction of all lines, which in the case of sodium refers to the D lines only, and this in flames no hotter than that of a Bunsen burner. If we apply the same line of reasoning to the appearance of the reversed hydrogen lines in the red and the blue, it may be stated that the line in the red, corresponding to solar line C, never appears in any hydrogen or hydrocarbon flame burnt with air or with oxygen. It invariably appears in sparks passed through steam, and it also comes out as a reversed line under suitable conditions in the Bessemer spectrum.

The conditions of its appearance do not depend upon an alteration in temperature, but on the presence of a sufficient amount of water-vapour in the blast.

This certainly seems to point to a higher temperature than that accorded to the flame by WATTS. Finally, we have this striking fact to consider: when slag from the converter is ignited at the highest temperature of the oxyhydrogen blowpipe, the red potassium, the red lithium, and the yellow sodium lines are present exactly as they are seen in the Bessemer-flame, but neither the orange lithium line nor the sodium pair 5681, 5687 appear; yet there must be a maximum amount of alkalies in the slag, or in other words all the alkali metals in the charge are concentrated in the slag—this maximum, however, being an extremely small quantity.

It is worth while to take into account the heat of combustion of the elements in pig iron which are removed during the "blow," and calculate, so far as data are available, the absolute heating effect of their oxidation. Any calculations of the kind must necessarily be incomplete, owing to the specific heats of gases at high temperatures being undetermined, though these have been lately investigated by BERTHELOT and VIEILLE,* also by MALLARD and LE CHATELIER.† The specific heats of molten iron and of ganister and slag are also wanting.

THE Combustible Elements in Pig Iron, with the Compounds formed, and their Heat of Combination ('Leçons sur les Métaux,' A. DITTE).

The names of the authorities are indicated as follows:—A., ANDREWS; T. and H., TROOST and HAUTEFEUILLE; F. and S., FAVRE and SILBERMANN; T., THOMSEN; B., BERTHOLLET; G., GRASSI.

Elements.	Atomic mass.	Kilo. heat-units developed from 1 grm. atom.	Compound formed.	Kilo. heat units developed by 1 grm. of each element.	Authority.
Cu	63·4	42·0	Cu_2O solid	0·662	T.
Mn	55·0	94·8	MnO ,,	1·72	T.
Si	28·4	219·2	SiO_2 ,,	7·7	T. and H., B.
C	12·0	29·4	CO gas	2·45	F. and S., G., A., T., B.
S	32·0	69·2	SO_2 ,,	2·2	F. and S., T., B.
P	31·0	363·8	P_2O_5 solid	..	T.
Fe	56·0	69·0	FeO	1·2	T.

In five tons of pig iron there are 5,080,240 grms. Let the composition of a pig iron be that which was quoted by BRUNNER, viz.:—

Mn . . . . 3·46 per cent. . . . . = 175,776 grms.
C . . . . . 3·18 ,, as graphite
Si . . . . . 1·96 ,, ... = 99,573 ,,
C . . . . . 0·75 ,, as combined carbon
Total carbon = 3·93 ,, ... = 199,653 ,,

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* 'Ann. de Chim. et de Phys.,' 6 ser., vol. 4, p. 66, 1885.

† 'Journ. de Phys.,' 2 ser., vol. 4, p. 59, 1885.

KILOGRAMME Heat-units evolved by the Combustion of the above Materials.

	Grms.		Kilo. heat-units evolved by 1 grm.		Total kilo. heat-units evolved by each element.
Mn	175,776	×	1·72	=	302,335
C	199,653	×	2·45	=	489,150
Si	99,573	×	7·7	=	766,712
					1,558,197

Kilogramme heat-units evolved by the combustion of the manganese, carbon, and silicon in five tons of pig iron = 1,558,197.

GRAMMES of Impurities eliminated from Five Tons of Pig Iron in the form of Gaseous Carbon Monoxide, solid Silica, and Manganous Oxide.

Grms.	Oxygen, grms.	Nitrogen, grms.
CO = 465,857	266,204	1,437,194
SiO_2 = 211,768	112,195	
MnO = 226,911	51,135	

SPECIFIC Heats for Equal Weights.

CO	0·245	Fe	0·11379
N	0·2438	Mn	0·1317
Si	0·175		

SPECIFIC Heat of the Materials in the Converter and of the Products of Combustion.

	Grms.		Sp. Heat.		Kilo. heat-units.
Weight of iron	4,605,238	×	0·11379	=	524·0
,, CO	465,857	×	0·245	=	114·1
,, N	1,437,194	×	0·2438	=	350·4
,, silica	211,768	These two substances form a slag.			
,, manganese oxide .	226,911				

The specific heat of glass, perhaps, approximates more closely to that of the slag than that of any other substance which has been determined. This is higher in the molten than in the solid state.

At 212° F. = $\overset{\text{Sp. Ht.}}{0{\cdot}177}$: at 572° F. = $\overset{\text{Sp. Ht.}}{0{\cdot}19}$.

The weight of the silica and the manganese oxide—

$$= 438{,}679 \text{ grms.} \times \overset{\text{Sp. Ht.}}{0{\cdot}19} = \overset{\text{kilo. heat-units.}}{83{\cdot}3}.$$

The total kilo. heat-units developed by combustion in the converter amount to 1,558,197, and the specific heat of the iron and the products of combustion, with also the nitrogen in the air, amounts to 1071·8 kilo. heat-units, and the pyrometrical effect is

$$t = \frac{1558197}{1071{\cdot}8} \text{ or } 1454^\circ \text{ C.}$$

The temperature attained, according to the foregoing calculations, amounts to 1454° C. above that of the molten cast iron. This, however, is the theoretical value; we must allow for the specific heats of the gases, the metal, and the slag being greater at the elevated temperatures than at the temperatures at which the numbers representing specific heats were determined.

The specific heat of the converter must be considerable, but it must be remembered that it is already heated to the temperature of the molten metal.

But even if we allow that 50 per cent. of the heat is absorbed or conveyed away, then we should have the temperature 727° C. above that of the molten pig iron, and thus with grey iron at 1220° C. the metal may acquire a temperature of more than 1947° C., which is above the melting point of platinum.

Judging by the number of lines and bands belonging to iron and manganese which have been photographed in the spectrum of the Bessemer flame, the temperature must nearly approach that of the oxyhydrogen flame, even if it does not exceed it in certain cases at the highest temperature of the "boil." At Dowlais, for instance, where the metal, which is very rich in silicon, carbon, and manganese, is just tapped from a hot-blast furnace and conveyed by rail in ladle to the converters, it is probably hotter at the commencement of the "blow" than if cold pig iron had been merely melted in a cupola.

The parallel columns below show the number of lines observed in the spectra of the respective substances under different conditions:—

Bessemer flame.	*Carbon monoxide burnt with oxygen.*
CO spectrum, 8 lines and edges of bands. Exposure $1\frac{1}{2}$ to 3 minutes	CO spectrum, 16 lines and edges of bands. Exposure 60 minutes.
	Oxyhydrogen blow-pipe flame.
Mn spectrum, 73 lines and edges of bands. Exposure $\frac{1}{2}$ to 3 minutes.	Mn spectrum, pure metal, 103 lines and edges of bands.
Fe spectrum, 92 lines. Exposure $\frac{1}{2}$ to 3 minutes.	Fe spectrum, 92 lines. Exposure from 15 to 30 minutes.

The temperature is to be judged by the iron lines, because there is a smaller difference in the proportion of the metal present in the two cases than in the case of the carbonic oxide and manganese. It is a striking fact that the Bessemer flame required a much shorter exposure than the oxyhydrogen blow-pipe flame, but the volume of flame is much larger; on the other hand, however, it is not so close to the instrument.

The following quotation* is of particular interest in connection with the temperature of the Bessemer "blow":—

"Les méthodes pyrométriques, dont j'ai entretenu à diverses reprises l'Académie, m'ont permis d'effectuer la mesure précise des températures développées dans les foyers industriels. Les résultats ainsi obtenus sont, pour certaines industries, en contradiction absolue avec les estimations faites antérieurement, et ne seront sans doute pas acceptés sans contestation. Je serais heureux si leur publication pouvait provoquer des expériences contradictoires sur le même sujet. . . . .

"Les températures données ici sont bien inférieures à celles qui sont le plus généralement admises pour les industries en question: 2000° pour l'acier; 1800° pour la porcelaine; 1200° pour le gaz d'éclairage. L'exagération de ces derniers chiffres tient à plusieurs causes. Entre différentes déterminations de températures non concordantes, on choisit de préférence les plus élevées, par suite d'un sentiment instinctif qui conduit á admettre une quasi-proportionnalité entre la température d'un corps et son éclat ou la quantité de combustible dépensé pour l'échauffer, tandis qu'en réalité ces deux grandeurs croissent suivant une fonction extrêmement rapide de la température. En second lieu, le procédé le plus fréquemment employé jusqu'ici dans l'industrie pour les mesures pyrométriques, a été la méthode calorimétrique, en se servant des morceaux de fer dont on supposait à tort la chaleur spécifique invariable. Enfin des causes d'erreurs particulières sont venues fausser des comparaisons dans lesquelles on utilisait le point de fusion du palladium ou du platine. Ainsi la température du Bessemer avait été fixé par LANGLEY à 2000°, parce que le platine paraissait fondre rapidement dans sa flamme. J'ai reconnu qu'il ne fondait pas, mais se dissolvait dans les gouttelettes d'acier fondu entraîné par le courant gazeux. De même, le palladium passe pour fondre dans différents fours où en réalité il se transforme, sans fusion, en une mousse spongieuse, par le fait d'hydrogénation ou d'oxydation passagère."

The cause of the Appearance of the Manganese Spectrum in all cases during the "Boil" and until the close of the "Fining stage."

There is one fact which requires to be explained in connection with the spectrum of the Bessemer flame. How can the characteristic lines and bands in the Bessemer spectrum be accounted for in all cases if they are not due to carbon or to carbonic oxide but to manganese? On an examination of the curves drawn from the analyses of SNELUS it will be observed that all the manganese is burnt out of the molten metal within the first few minutes and converted into slag. It is obvious that the manganese bands cannot in these circumstances proceed from the bath of metal up to the end of the "fining stage" if the quantity required to give a marked indication of them is comparatively large. The sole source of the manganese bands must be a quantity of metal reduced from the slag, this reduction cannot take place at once, but is the result of a continously increasing temperature and the chemical action of reducing materials such as ferrous carbide, carbonic oxide, and possibly metallic iron.

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* LE CHATELIER, "Sur les températures développées dans les foyers industriels," 'Comptes Rendus,' vol. 114, p. 470.

In order to ascertain whether slag could be reduced and give rise to the characteristic spectrum of the Bessemer flame, a piece of slag from the works at Crewe was heated by the oxyhydrogen blow-pipe both in the inner and outer flames, that is to say, where in the latter case reduction could take place by dissociation by heat alone, but in the former it might be aided by chemical action of the excess of hydrogen. The photographs obtained were strikingly like those from the Bessemer flame at Crewe.

Comparing it with ferro-manganese, we have band for band belonging to manganese, and line for line in the iron spectrum, exactly reproduced. There can be no doubt whatever that both iron and manganese are freely volatilized from the slag. Considering the small proportion of manganese in hæmatite pig, and the fact shown in Diagram I, that the manganese in such metal is all converted into slag during the first five or six minutes, it is evident that the continued brilliancy of the manganese spectrum during the "boil" must be entirely due to its vaporization from the slag.

In order to connect the disappearance of this spectrum with the chemical change involved in the decarburization of the iron, we must consider the falling off in intensity of the line spectra during the close of the "fining stage," before the final drop of the flame, and it will be seen that this can clearly be due to no other cause than a fall of temperature, consequent upon a reduction in the quantity of carbon burnt. The thinness, transparency, and want of brilliancy in the flame at this period is due to the comparatively small quantity of carbonic oxide in the issuing gas; the final drop being caused by an escape of oxygen into the vapours and gases within the converter, which is signalized by a cloud of fume. The removal of the carbon from the metal causes the disappearance of the manganese bands.

Let us now consider the case of the Dowlais "blow."

The spectrum of the flame in this case resembles strongly the spiegel-eisen spectrum, and those of metallic manganese and ferro-manganese. There can be no doubt that manganese is vaporized in the bath of metal, and hence the large number of bands, their distinctness, and great brilliancy. The diagram of KUPELWIESER's analysis will make this plain, for here we have an excess of manganese in the iron, which, though oxidized during the "slag-forming period," continues to be vaporized during the whole remaining period of the blow, this metal being of similar composition to that blown at Dowlais.

It must, however, be remembered that the higher temperature at Dowlais would, if acting upon manganese slag, produce a spectrum more similar in character to that obtained from ferro-manganese or spiegel-eisen than that obtained at Crewe, but the iron lines in these circumstances would also be stronger.

The connection between the termination of the blow and the drop of the flame is to be explained exactly as in the case of the spectrum at Crewe, the difference in the two spectra being due to the quantity of vapour of manganese in the flame.

The Technical Aspect of this Investigation.

Long experience has shown that in England, in Styria, and at Seraing, in Belgium, the use of the spectroscope has rendered substantial service in determining the end of the operation in the Bessemer converter, notwithstanding that the nature of the spectrum observed was not accurately ascertained, nor the cause of its production well understood. The reason of this is not far to seek, when we consider that towards the close of the "fining stage" the indication is particularly distinct, for it culminates in the disappearance of the bright lines and flutings of manganese, whether these proceed from the presence in the flame of material vaporized directly from the metal itself, or from the slag which is formed from the oxidation of elements contained in the metal during the first period. The quantity of grey cast iron, of spiegel-eisen, or ferro-manganese, which is finally added, determines the hardness of the steel, and the composition of the added material is ascertained with exactitude by means of frequent analyses.

By this means a metal is obtained which is much more constant in composition than when the process is interrupted before the completion of decarburization, and when, after the result of a test of the metal, spiegel-eisen is added and blowing is resumed for a few minutes. It was the aim of managers of steel works in the early days of the process to cease blowing before complete decarburization, in order that the necessary proportion of carbon might be left in the charge; but it was found that there was no certainty in being able to produce the same quality of metal at each "blow." It will be seen from the results of this investigation that the thermo-chemical operation involved in blowing could not be always carried out exactly under the same conditions, or within the same precise limits of time; the initial temperature of the metal, and even the temperature of the converter into which the charge is allowed to flow, can affect the rate of combustion of the carbon, and the oxidation of the manganese and silicon; and, furthermore, it must be borne in mind that, with successive charges from the same blast-furnace, the composition of the metal varies to an extent which can easily upset all previous calculations. When the charges come from different furnaces, further complications and increased difficulties arise. As there is no indication, except at the close of the "fining stage," when the carbon remaining unburnt is reduced to a very small proportion of that originally present, it is quite evident that the most rational and practicable mode of operating is to remove it all, and then to add a sufficiency of a carburized metal which will produce a steel of the required hardness and composition; since both by the appearance of flame and fume, as well as by spectroscopic analyses, the complete termination of the "fining stage" is clearly indicated.

The constitution of the Bessemer-flame spectrum, as established by this investigation, and the cause of the continued appearance of the manganese bands and iron lines, even after all the manganese has been removed from the metal, which has been explained, affords scientific reasons for not only continuing to pursue the course which has been universally adopted, but of not departing therefrom. The practice of complete decarburization is most rapidly and exactly carried out, and it has yielded, and continues to yield, enormous quantities of mild steel or soft iron, in a high state of purity and of remarkable constancy in composition.

Summary and Conclusions.

1. The complex nature of the Bessemer-flame spectrum is owing to the superposition of bands of manganese, carbon, carbonic oxide, possibly also of manganese oxide, and of the lines of iron, manganese, potassium, sodium, lithium, and hydrogen. The bands of manganese are to some extent obscured, first, by the strong continuous spectrum of the carbonic oxide flame, secondly, by the bands of carbon; for, while the manganese bands are degraded towards the red, the overlapping carbon bands are degraded in the opposite direction, that is, towards the blue.

2. The cause of the non-appearance of the lines in the spectrum at the beginning of the "blow" is the comparatively low temperature at this period, very little above that of the molten metal, and the free oxygen that escapes with carbon dioxide, giving a gaseous mixture which contains too small a proportion of carbonic oxide. The alkalies come from the ganister brick lining of the converter, and therefore exist as silicates present in very small proportion. Silicates—such, for instance, as felspar—do not readily disclose the alkalies they contain until heated in the oxyhydrogen flame, but at this high temperature the metals potassium, lithium, and rubidium have been detected with the greatest ease in such silicates. Similarly, the alkali metals do not show themselves in the flame until a layer of slag has been formed, and the temperature has risen sufficiently high for the constituents to be vaporized.

3. There can be no doubt that at the temperature of the "boil" both metallic manganese and iron are freely vaporized in a current of carbonic oxide, which, in a highly heated state, rushes out of the bath of molten metal. The evidence of this is the lines and bands of iron and of manganese, photographed and compared with the lines and bands in the spectra of various alloys of iron and manganese.

4. The question of vaporization of manganese and of manganese oxide from slag is put beyond all doubt by actual experiment with the oxyhydrogen blowpipe flame. This explains the fact observed by BRUNNER, namely, that when a converter is being heated with coke after it has been used, but not re-lined, the spectrum of the Bessemer flame makes its appearance.

5. The luminosity of the flame during the "boil" is due, not only to the combustion of highly-heated carbonic oxide, but also to the presence of the vapours of iron and manganese in the gas.

6. The disappearance of the manganese spectrum at the end of the "fining stage" is primarily due to a reduction in the quantity of heated carbonic oxide escaping from the converter, which arises from the diminished quantity of carbon in the metal. When the last traces of carbon are gone, so that air may escape through the metal, the blast instantly oxidizes any manganese either in the metal or in the atmosphere of the converter, and furthermore oxidizes some of the iron. The temperature must then fall with great rapidity.

7. The entire spectroscopic phenomena of the "blow" are undoubtedly determined by the chemical composition of the molten iron and of the gases within the converter, the temperature of the metal, and of the issuing gases.

8. The probable temperature of the Bessemer flame at the finish is that produced by the combustion in cold air of carbonic oxide heated to 1580° C.; that is to say, to the temperature which, according to LE CHATELIER, is that of the bath of molten metal from which the gas has proceeded. The bath of metal acts at the same time as a means of heating the blast, producing the gas, and as a furnace on the regenerative principle which heats the gas prior to its combustion.

9. If we may judge by the lines and bands belonging to iron and manganese which have been measured in photographed spectra of the Bessemer flame, the temperature must nearly approach that of the oxyhydrogen flame, and may easily attain the melting-point of platinum.

10. The spectrum obtainable from Bessemer slag by the oxyhydrogen flame is composed of precisely the most characteristic features of the flame-spectrum, as seen issuing from the converter at Crewe. The continuous spectrum of carbonic oxide, bands and lines of that compound, and of elementary carbon, are, as a matter of course, absent.

The flame at Dowlais differs from this, and resembles the spectrum of metallic manganese. These differences may not be entirely due to the higher temperature at Dowlais, but to the difference in composition of the metal. The manganese at Crewe would be oxidized to slag within the first seven minutes—that is say, before the manganese spectrum makes its appearance in the flame. That at Dowlais would probably not be all removed from the bath of metal by oxidation before the end of the "blow." The former yields such a spectrum as may be obtained from slag, the latter, one which is obtainable only from spiegel, ferro-manganese, or pure metallic manganese. There can be no doubt that, in blowing hæmatite pig, the spectra of manganese and iron may be caused by the volatilization of these elements from the slag.

11. The complete termination of the "fining stage" is clearly indicated, but there is no indication by the flame of the composition of the metal within the converter at any previous stage.

As the progress of the "blow" is governed by the composition of the metal and its temperature in the converter, and as these cannot be controlled with perfect exactitude during each "blow," it follows that the practice of complete decarburization is the best course to pursue, the required amount of carbon and manganese being added subsequently.

I desire to record an expression of my thanks to Mr. F. W. Webb, of the Crewe Works, and Mr. E. P. Martin, of Dowlais, for the facilities they have afforded me in making these observations; to the Government Grant Committee, for the means of carrying out this investigation; and to Mr. Hugh Ramage, my assistant, for the care he has exercised in carrying out my instructions, in executing the photographs and measuring some of the spectra.

I propose to pursue the work in another direction, by extending a series of observations to the basic Bessemer "blow," the blast-furnace, and various forms of Siemens steel furnaces.